THE TASMANIAN CETACEAN STRANDING RECORD:

A REVIEW OF THE CETACEAN STRANDINGS IN TASMANIAN WATERS AND AN EXAMINATION OF POSSIBLE CAUSES.

Being a thesis submitted in fulfilment of the requirements for the degree of Master of Environmental Studies (Research).

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This thesis contains no material which has been accepted for the award of any other degree or diploma in another university and to the best of my knowledge contains no copy or paraphrase of material previously published or written by any other persons, except where due reference is made in the text.

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September 1991

DEDICATION

This thesis is dedicated to Dr Richard (Dick) Jones who died, unexpectedly, in March 1986.

Dick Jones was my first supervisor and had an important and lasting influence on the overall direction of my work and the Whale Stranding Research Project. It was through Dick Jones' efforts that the Arthur Boyd Fellowship was made available at the Centre for Environmental Studies, enabling me to study the phenomenon of whale strandings. His guidance, leadership and friendship have had a lasting effect upon my work and myself. It is therefore fitting that this thesis is dedicated to the memory of Dick Jones.

DOUGLAS J. NICOL

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ABSTRACT

Tasmanian cetacean stranding reports are examined and reviewed to establish the composition of the record and identify possible causes of the strandings. The record, to the end of February 1986, comprises 213 stranding events (152 single and 61 herd strandings) dating from 1825. These events involve 22 species and over 3000 animals. Five species (the pygmy right whale, sperm whale, long-finned pilot whale, common dolphin and bottle-nosed dolphin) have each stranded on more than 20 occasions, and represent 66% of the events. Four species (the false killer whale, strap-toothed whale, Cuvier's beaked whale, and Gray's beaked whale) have each stranded between nine and 13 times. The remaining 13 species have stranded on less than five occasions, usually only once each, and there are nine strandings in the record for which the species involved is not known.

In general, areas with high numbers of strandings have complex oceanographic conditions. It is proposed that the high number of strandings on the western section of the north coast of Tasmania, and the Storm Bay - southeast area are due to cetaceans experiencing difficulties with the combination of the areas' oceanographic conditions and extensive shoaling waters, while the low number of strandings in the central section of the north coast is due to the low number of cetaceans that enter the shallow central region of Bass Strait.

Active strandings are shown to occur predominantly on shelving coasts, the frequency of which is significantly higher than that expected from the proportion of these topographies along the coast as a whole. This relationship does not exist on the north coast because of the high proportion of beaches in this area, indicating that steep coasts may prevent strandings rather than shelving coasts causing them. Active stranding sites tended to occur at or near local minima in the geomagnetic field intensity but they were not characterised by having intensity contours running perpendicular to the coast's alignment.

The stranding record shows a strong seasonality with most events being reported during the summer months. It is proposed that a major influence is that the summer months are the peak period of human activity on the beaches, thus a period of high observer effort. Long-finned pilot whale strandings are significantly correlated with sea surface temperature, possibly indicating that part of the seasonal pattern is induced by seasonal variations in the physical environment.

The overall long-term trend are of more strandings being reported each year, and it is proposed that the increase is due to greater scientific interest and public awareness of cetacean strandings rather than changes in the actual rate of strandings. The annual fluctuations in the number of stranding reports, however, can not be explained by variations in observer effort. Several environmental factors were investigated including aspects of the Tasmanian weather, variations of, and disruptions to, Tasmania's oceanography, and the disruption of the navigation systems of cetaceans. Only strandings of two species and two species groups were significantly correlated with some of these features, at varying time lags (-1, 0, +1 years), which indicates that either the availability or susceptibility of cetaceans to strand is affected by some features of the physical environment around and to the south of Tasmania.

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CHAPTER 1 INTRODUCTION

The stranding of whales and dolphins (collectively called cetaceans) upon the beaches of the world is one of the mysteries of nature that has fascinated people for at least as long as recorded history (for example see Aristotle 335BC) and probably for much longer (see Slijper 1979 for discussion of earliest known non-written records of human-cetacean interactions). Humans may have began to utilize cetaceans as food through the opportunistic discovery of stranded cetaceans (Slijper 1979). A major part of the fascination has been with explaining why creatures of the deep ocean should cast themselves ashore, often in what appeared to be a deliberate manner. Explanations range from those of the Romans, who thought the animals had been forced ashore by Neptune as punishment (Cordes 1981, 1982), suicide (Geraci 1978), a primeval instinct to seek safety on land during periods of stress (Wood 1979), navigational errors (Klinowska 1985b, 1986a, 1986b, 1986c, 1987) and behavioural problems (Robson 1976, 1984; Warneke 1983, 1986).

A second aspect of this fascination has been with the creatures themselves. Strandings represented the only source of information about cetaceans available to early scientists, particularly for the larger species (Berzin 1972; Slijper 1979) until the beginning of scientific expeditions in the eighteenth century and the development of whaling industries (Crowther 1920; Watson 1981). Strandings today still provide an important, and often the only, source of information about many of the rare and elusive oceanic whales (International Whaling Commission 1986; Warneke 1986). The bulk of scientific interest in stranded cetaceans concentrated on the animals rather than the causes of the events, partly because this aspect is easier to deal with. Nevertheless, the identification of the species is an important part of any investigation into the causes of cetacean strandings.

In recent years, the degree of public awareness of, and concern for, cetaceans has increased due to the debate about the conservation of cetaceans (Frost 1978; Bittelman 1982; Whiteside 1985). With the cessation of whaling in Australia in 1978 much of this awareness and concern began to be directed towards stranded cetaceans with effort being devoted to their rescue (Anderson 1982, 1985; Ling 1981; Bittelman 1982; Whiteside 1985, 1987). This led to the development of contingency plans for cetacean strandings at both the State (McManus *et al.* 1984; Warneke 1986) and national levels (Anderson 1982, 1985). Similar developments occurred in other parts of the world (Geraci and St Aubin 1979a; Baker 1981b, 1981d; Barzdo

1985). An important factor associated with such plans were calls for more scientific research into cetacean strandings, including the causes of such events.

Within Australia, one outcome of the calls for more research was the establishment of the "Arthur Boyd Fellowship" by the Australian Museum, as a result of a donation by the Australian landscape painter Arthur Boyd. The fellowship was to enable research into cetacean strandings to be conducted. It was based in Tasmania due to the large number of stranding events that have occurred there.

This thesis presents the result of the research conducted under the auspices of the fellowship and has the overall objectives of investigating cetacean strandings around Tasmania to establish the cause(s) of these events and develop ways of preventing cetaceans from stranding. To meet these objectives five major aims have been identified:

1) review the scientific literature on hypothesis for cetacean strandings;
2) establish the Tasmanian cetacean stranding record, including confirmation of species identification and other details;
3) identify patterns within the stranding record including relative abundance of each species, and variations in distribution and rates of strandings (seasonal and long term);
4) examine these patterns for possible influences of a) humans, b) environmental features and c) the cetaceans themselves; and
5) determine the cause(s) of cetacean strandings around Tasmania.

The review of the literature on cetaceans and their strandings includes the development of a working hypothesis for the study (Chapter 2). Then, the Tasmanian cetacean stranding record was established and the influence of human activity effort upon the record was determined (Chapter 3). Detailed examination of the spatial (Chapter 4) and temporal patterns (Chapter 5) in search of environmental influences were then conducted. The results are discussed in light of the known biology and behaviour of the cetaceans. The final chapter summaries the results and major conclusions of the study, and re-examines the study's working hypothesis. An integrated data collection procedure was developed to maximise the data collected for the minimum effort while providing data necessary for future examinations of cetacean strandings (Appendix III).

CHAPTER 2 CETACEAN BIOLOGY AND THE STRANDING PHENOMENON

2.1 INTRODUCTION

This chapter reviews the scientific literature on cetacean strandings, particularly the many hypotheses. The principal aims of this chapter are to provide a background to the subsequent examinations, introduce terminology and develop a working hypothesis for this study. The first section of the review consists of a very short summary of relevant aspects of cetacean biology. The second section examines the stranding hypotheses which involve a range of factors from the environment, and the health and behaviour of the cetaceans.

2.2 CETACEAN BIOLOGY AND ECOLOGY

2.2.1 INTRODUCTION

The order Cetacea is divided into two sub-orders, baleen whales (Mysticeti) and toothed whales (Odontoceti). The major differences between the sub-orders are in the structure of the head, the mouth parts and the number of blowholes (Watson 1981; Gaskin 1982; Baker 1983).

Cetacean taxonomy is still debated. An outline of the taxonomy of the cetaceans mentioned in this study is given in Appendix I. The differences between the two sub-orders lead some authors to propose separate evolutionary origins (Slijper 1979). Recently, researchers tend to support a single origin with differences between, and within, the sub-orders reflecting subsequent evolutionary divergence (Gaskin 1982; Fordyce 1984, 1985).

2.2.2 GENERAL BIOLOGY

Cetaceans have evolved many adaptations for their aquatic lifestyle mainly relating to the increased density of water with consequences for mobility, physiology and sensory systems. Further details of cetacean biology and ecology can be obtained by consulting Slijper (1979), Watson (1981), Gaskin (1982), Bryden and Harrison (1986), and Evans (1987).

2.2.2.1 MOBILITY

Cetaceans have development a streamlined body shape having lost their hind limbs and with the fore limbs, or flippers, being reduced. Most cetaceans have a dorsal fin, which is thought to increase stability (Watson 1981; Gaskin 1982).

The horizontal tail flukes are the major source of propulsion. Lateral movement of the body is restricted, although mobility varies between species. Cetaceans are unable to move backwards and many can only manoeuvre quickly while moving forward (Dawson 1985). These restrictions have important implications for animals entering shallow and restricted waters.

2.2.2.2 BUOYANCY

The buoyancy provided by water has lead to decreased bone density and the loss, or reduction, of supportive tissues for internal organs (Watson 1981). Both these can cause considerable problems, physically and physiologically, to stranded cetaceans. Bones break relatively easily and increased pressure from the animals' weight damages internal organs, restricts blood circulation and impairs respiration (Geraci 1978; Kirk 1981). These effects, coupled with shock, can lead to cardiopulmonary failure and death in stranded cetaceans (Cowan *et al.* 1986).

2.2.2.3 PHYSIOLOGY

The energy flux of water is about 40 times greater than air, causing higher rates of heat loss from cetaceans. Cetaceans compensate by conserving energy through the combination of their cylindrical body shape, an insulating layer of blubber plus special counter-current blood vessel networks around arteries leading to, or near, the skin. The basal metabolic rate of cetaceans is not higher than normal but extra physiological energy is generated by constant swimming (Kanwisher and Ridgway 1983; Ridgway and Harrison 1986). Extra metabolic energy generated during periods of high activity can be dispersed by increased blood flow near the skin. Dorsal fin, flippers and tail flukes are important sites of heat exchange (Gaskin 1982; Kanwisher and Ridgway 1983; Ridgway and Harrison 1986). Stranded cetaceans can rapidly overheat, which eventually kills them (Geraci 1978; Kirk 1981; Cowan *et al.* 1986).

2.2.2.4 Sensory Systems

Cetaceans have six senses: auditory, visual, sensory (tactical), chemoreceptive (taste and smell), magnetic, and balance/body co-ordination (Dawson 1980; Popper 1980; Dawson 1985; Klinowska 1987; Kaufman and Forestell 1986; Evans 1987). Hearing is the primary sense of cetaceans since the levels of light are reduce with depth and increased turbidity (Dudok van Heel 1962; Thompson *et al.* 1979). Hearing is most highly developed in the echo-location systems of toothed whales, where high frequency clicks are emitted in a directional beam, and changes in frequency and timing of returning signals indicate the location of, direction of travel of and other objects in their surrounds (Morris 1986). Baleen whales may also be able to echo-locate, although they appear to only use low frequencies sounds which would be useful in locating large scale features, such as submarine topography (Thompson *et al.* 1979). Hearing occurs through either the external auditory passages or the lower jaw (with its associated fat deposits) (Popper 1980; Purves and Pilleri 1983; Morris 1986).

Cetaceans see effectively above and below the surface (Dawson 1980; Madsen and Herman 1980; Evans 1987). In water, the cetacean eye has a wide focal range due to the shape of its lens, called a "fish eye". Cetaceans can see in air because a section of the lower surface of their lens is flattened, which enables light to be focused on the retina (Dawson 1980; Kaufman and Forestell 1986; Evans 1987).

Cetacean use touch in social interactions and to investigate their environment. Cetaceans have several areas of heightened sensitivity, notably the lips, genital areas, sensory nodules on the head (not on all species) and areas on the flippers (Gaskin 1982; Evans 1987).

Chemoreception is not well developed in cetaceans, with no evidence of any olfactory capacity (Lowell and Flonigan 1980; Watson 1980). There is some limited ability for taste, as shown by the mouthing of food items before their rejection or acceptance. Cetaceans may also be able to distinguish between water bodies by detecting differences in salinity (Lowell and Flonigan 1980; Watson 1980; Gaskin 1982).

There is a growing body of evidence that cetaceans can detect the earth's magnetic field (Zoeger *et al.* 1981; Bauer *et al* 1985; Klinowska 1985b, 1986a, 1986c, 1987; Dawson *et al.* 1985; Cornwell-Huston 1986; Kirschvink *et al.* 1986; Walker *et al.* 1986). Cyclic variations in the earth's magnetic field may also be important as time-cues for biological clocks (Brown 1976a, 1976b; Klinowska 1986a, 1986b). A time sense is important for navigation as it enables animals to estimate progress. Orientation based on a magnetic sense could be the primary long range navigation system for cetaceans (Klinowska 1985b, 1986a, 1986b; Cornwell-Huston 1986; Kirschvink *et al.* 1986; Walker *et al.* 1986).

2.2.3 BALEEN WHALES

Baleen whales are subdivided into three families; right whales (Balaenidae) with four species in three genera, rorqual whales (Balaenopteridae) with six species in two genera, and gray whales (Eschrichtiidae) with a single species (Gaskin 1982; Baker 1983; Leatherwood and Reeves 1983).

Baleen whales feed by filtering zooplankton from the water passing through a series of horny plants, the baleen, that hangs from the edges of the top jaw. Most baleen whales feed in the highly productive polar, sub-polar and cold temperate seas during the summer. They migrate to temperate or tropical seas for calving and mating during the winter. The extent of these migrations varies with the species, populations and individuals involved (Dawbin 1956, 1966, 1983; Slijper 1979; Watson 1981; Gaskin 1982).

Baleen whales are primarily solitary animals. The cow-calf pair is the only long-term social unit which lasts less than a year (Gaskin 1982; Whitehead 1983; Kaufman and Forestell 1986). Baleen whales periodically form short-term aggregations, thought to be related to prey abundance rather than social activities (Gaskin 1982; Kaufman and Forestell 1986). During migration whales occasionally travel in small groups, but the durability of these groups has yet to be established (Gaskin 1982; Kaufman and Forestell 1986).

The distributions of baleen whales on feeding grounds are often related to their prey which, in turn, are influenced by various oceanographic and geographic features, such as fronts, upwellings and convergence zones (Omura and Nemato 1955; Uda and Dairokuro 1958; Gaskin 1982; Whitehead and Carscadden 1985), and shallow banks, pinnacles and sheltered bays and inlets (Gaskin 1982; Dawbin 1983).

2.2.4 TOOTHED WHALES

Toothed whales, as the name implies, have teeth, although in some species the teeth erupt only in mature males. Toothed whales are a diverse suborder with six families and about 65 species

(Baker 1983: Leatherwood and Reeves 1983). The largest family, with 16 genera and 31 species, is the dolphins (Delphinidae). The most unusual and least studied toothed whales are the beaked whales (Ziphiidae). This family has five genera and 18 species, of which 12 species belong to one genus, *Mesoplodon*. The largest toothed whale, the sperm whale (*Physeter macrocephalus*), is in the family Physeteridae along with diminutive sperm whale species. True porpoises (Phocoenidae) include four genera and six species (Barines 1985). The family Platanistidae, the freshwater dolphins, has four genera and five species. The final two species, the arctic whales, are in the family Monodontidae.

Toothed whales feed on fish and/or cephalopods, with killer whales (*Orcinus orca*) also feeding on marine mammals, including other cetaceans (Gaskin 1982; Clark 1986). Variations in diet are reflected in the diversity of teeth, feeding behaviour and distribution. Toothed whale species that have few teeth tend to feed predominantly on cephalopods (Gaskin 1982; Norris and Mohl 1983) while species with large numbers of teeth, mainly small dolphins, feed predominantly on fish (Gaskin 1982).

It is clear that some toothed whales can echo-locate, being able to distinguish between slightly different objects, locate and identify prey and predators, and undertake short-range navigation. Echo-location could be used in mid to long range navigation (Dudok van Heel 1962, 1966; Norris 1967; Lockyer and Brown 1981; Gaskin 1982; Morris 1986). Long range orientation will use echo-location as well as hearing (detecting noise from surf), sight (landmarks and celestial navigation) and aspects of the geomagnetic field (Norris 1967; Lockyer and Brown 1981; Gaskin 1982; Klinowska 1985b, 1986a, 1987; Cornwell-Huston 1986; Kirschvink *et al.* 1986; Walker *et al.* 1986).

Toothed whales do not undertake seasonal migrations of similar magnitude to baleen whales. Rather, their distributions vary seasonally, with populations moving either north/south or inshore/offshore. Individuals may travel several hundred kilometres during a few days but they tend to remain in the same general area (Evans 1974; Hui 1979; Gaskin 1982). Mature male sperm whales are an exception as they often feed in high polar seas during summer, migrating back to the tropics for the breeding season (Best 1979; Gaskin 1982). Prey distributions are the major influences on the distributions of toothed whales which are related to oceanographic features, such as fronts, upwellings and convergence zones (Gaskin 1968, 1971, 1982; Best 1979).

Toothed whales display a very diverse range of social organisations. Some species are basically solitary, others form small stable family units, and still other species are highly gregarious and regularly form large arrigations (Frazer 1976; Norris and Dohl 1980; Wells *et al.* 1980; Gaskin 1982). Toothed whales have several different types of schools in their social structures, including single sex schools (often all males and called "bachelor schools"), mixed sex schools of adults accompanied by immature animals and calves (called "harem schools"), and schools of mature females with calves but without mature males (called "nursery schools") (Frazer 1976; Norris and Dohl 1980; Gaskin 1982). The basic social unit for sperm whales are the nursery schools (Gaskin 1964, 1970, 1982; Best 1979; Whitehead and Arnbom 1987), while for the pilot whales the harem school is their basic social unit (Kasuya and Marsh 1986).

The highly social toothed whales display a considerable degree of cooperation during feeding and predator avoidance (Norris and Dohl 1980; Watson 1981; Gaskin 1982). This reaches its greatest developed in epimeletic behaviour ("care-giving"), where whales assist ill or distressed animals often in life-threatening situations for both animals (Caldwell and Caldwell 1966; Connor and Norris 1982; Pilleri 1984). This behaviour may play an important role in explaining why whales, other than the initial strander, come ashore during herd strandings (see Section 2.3.3.3).

2.3 STRANDING PHENOMENON

2.3.1 INTRODUCTION

Twenty two hypotheses dealing with cetacean strandings are reviewed with the intention of producing a working hypothesis for use in examinations of Tasmanian cetacean strandings. The central components of each hypothesis are listed in Table 2.1. The hypotheses are grouped into three broad categories based on their principal components, being physical environment, ill health and behaviour. The explanations range in scope from those dealing with a limited set of events through to attempts to provide a unifying theory for all strandings. The critical analysis applied to the hypotheses varies considerably between authors.

During the past decade major meetings on cetacean strandings, their causes and management, have been held in the USA (Geraci and St Aubin 1979a), New Zealand (Anonymous 1981), Australia (Ling (1981) and the UK (Barzdo 1985). In addition, several authors have reviewed the literature on cetacean strandings and their causes (Geraci 1978; Best 1982; Warneke 1983; Dawson 1985). Robson (1976, 1984) has produced two interesting works on cetaceans and their strandings, the result of a lifetime of experience and observation of cetaceans on the beaches and in the waters around New Zealand. These publications, along with the numerous articles describing single events or aspects of several events, form the basis of this review. It should be noted that while some of the review papers cover a wide range of hypotheses it does not necessarily mean that the respective authors support all hypotheses they mention.

2.3.2 TERMS AND DEFINITIONS

Cetacean strandings include many different types of events, from the washing ashore of a long-dead carcass to the active (and often repeated) stranding of several hundred animals. To enable scientific evaluation of these various events, it is necessary to classify the data. Klinowska (1985a) thought it unlikely that any single system could adequately cover all stranding events while remaining biologically meaningful.

The present study, besides grouping animals into their taxa, uses two complementary classification systems. The first system is based on the number of animals involved in each event and may be a reflection of the species' social structure. It has two groups: **single**

TABLE 2.1

EXISTING HYPOTHESES FOR CETACEAN STRANDINGS

TYPES OF HYPOTHESES			Evaluation of Hypotheses
PHYSICAL ENVIRONMENT			
	Weather		✚ ✓
	Topography	geographic	✚ ✓
		geomagnetic	✚ ✓
	Oceanography		✚ ✓
	Human induced		✚ ✓
HEALTH OF THE ANIMALS			
	Disease		✚
	Parasites		✚
	Starvation		✚
	Injury		✚
	Population density		✖
BEHAVIOUR			
	Compulsion		
		fear of drowning	✖
		instinctive compulsion	✖
		suicide	✖
	Errors of Judgement		
		predator avoidance	✚
		chasing prey	✚
		ancestral pathways	❊
		navigational errors	✚
		social upheavel	✚
	Tactle Stimulation		✖
	Herd Strandings		
		mass error	❊
		follow the leader	❊
		social cohesion	✚

NOTES

✓ = tested in this study

✚ = part of the overall working hypothesis

❊ = not included in the overall working hypothesis

✖ = untestable hypothesis

strandings (including mother-calf pairs), and **herd strandings** (two or more animals other than mother-calf pairs). The term "herd stranding" was initially proposed by Robson (1984) to indicate the underlying social causes of these strandings unlike the previously used term "mass stranding" which implies only that more than one animal was involved. It should be noted that the term "herd", as used in this study, may not meet the strict definition used in behavioural studies, that is a discrete group of animals that are related together by the performance of a common behaviour or activity (Gaskin 1982). Therefore, when an event is described as being a "herd stranding", this shows that more than one animal was involved and the reasons behind the involvement of the additional whales may have been "social cohesion". However, the use of "herd" is not intended to imply that all the animals came from a single social unit (a herd or school).

The second classification system is based on the health status of the animals at the time of stranding and many reflect the involvement of the stranding site in causing the event. This system has three categories: **active stranding** (animals alive at the time of their stranding, including moribund animals), **passive strandings** (animals dead before stranding), and **undetermined strandings** (strandings discovered after the event and for which the health status could not be determine).

Strandings involving more than one animal (herd or mother-calf pairs) are considered active events as it is likely that, at least, some animals were alive when they stranded. This assumption needs to be treated with caution. For example, in the United Kingdom, some cetaceans found stranded together had been killed during fishing operations then washed ashore (Klinowska 1985a). Such events do not appear to have occurred in Tasmania, only two events in the stranding record involved animals killed during fishing operations: both were single passive strandings of common dolphins at Eaglehawk Bay in January and February 1984 (Nicol 1987).

2.3.3 EXISTING HYPOTHESES

As noted in the introduction there are three basic categories of explanations reflecting the major factor involved in each hypothesis. The divisions between these categories are not fixed, rather, explanations may involve factors from different categories.

2.3.3.1 PHYSICAL ENVIRONMENT

The following hypotheses have aspects of the physical environment, such as weather, topography (both geographic and geomagnetic), oceanographic or human related factors (harassment and pollution), as the major causal factor(s) of cetacean strandings.

WEATHER

Three general hypotheses have weather as the principal cause of some cetacean strandings. Wind and wind-generated waves transport animals ashore (this mainly applies to dead or moribund animals; Geraci and St Aubin 1979a; Kayes 1985; Klinowska 1985a), violent storms force animals to run before them and if cetaceans are on the landward side of a storm they may strand (Robson 1976, 1984; Geraci 1978; Wood 1979; Cordes 1981, 1982; Barzdo 1985), or electrical discharges associated with storms disorientate animals, disrupting their communication systems, adding to any confusion caused by the storm (Robson and van Bree 1971; Robson 1976; 1984).

TOPOGRAPHY

These explanations involve aspects of both geographic and geomagnetic topographies, and they deal with two features of stranding records; most active strandings occur on gently shelving beaches and strandings are clumped, with sections of coast recording greater numbers of strandings than the surrounding coasts (Geraci and St Aubin 1979a; Mead 1979; Sheldrick 1979; Baker 1981a; Warneke 1983; McManus *et al.* 1984).

Geographic

Dudok van Heel (1962, 1966) note that gently shelving beaches and tidal flats are common sites for herd strandings. He proposed that such types of coastal topography do not return strong echo-location signals, leading animals to mistakenly perceive that the way ahead was clear. Dudok van Heel suggested that two features of these topographies cause the poor reflections, they deflect sound away from rather than towards the source and suspended material in the turbulence layer just above the bottom on shelving coasts scatters sound.

At least five problems have been identified with this theory. Active strandings do not occur *exclusively* on gently shelving coasts; for instance Klinowska (1986a) reported that 36% of the active strandings reported from around the UK occurred on steep coasts. Recent studies of the echo-location abilities of cetaceans in the wild (Morris 1986) indicate that they are very sophisticated, being able to detect nearby coasts, even if only be changes in water depth. The echo-location reflections from shelving beaches were found to be strong (Geraci 1978). Cetaceans are unlikely to rely on a single source of information when other indications of an approaching coastline are available, such as changes in the shape and nature of waves, and the noise generated by surf (Norris 1967; Locker and Brown 1981; Gaskin 1982). Finally, the structure of gently shelving beaches and tidal flats may influence, or cause, cetacean strandings without the involvement of echo-location signals.

Once a stranding has occurred on shelving coasts the animals are more likely to remain ashore, with a greater chance of discovery. On shelving coasts, cetaceans have difficulty refloating themselves since they can only roll over which would not gain them significant water. On steep coasts, rolling over may increase the depth of water sufficiently to enable the animals to regain their buoyancy and swim away. During a stranding of sperm whales at the entrance to Macquarie Harbour, Tasmania, an adult rescued herself by rolling off a sandbank into a deep channel (Rounsevell *et al.* 1981; McManus *et al.* 1984).

Two features of shelving coasts also increase the likelihood of the subsequent discovery of strandings. These coasts are subjected to lower levels of wave energy than surrounding steep coasts (Dartnall 1974; Beer 1983), thus, carcass would remain ashore longer on beaches. Gently shelving beaches generally have easier access than nearby steep coasts and greater recreational use, thus observer effort would be higher.

To explain why some sections of a coast have high numbers of strandings, several authors have suggested that the combination of topographies in these areas facilitate, even cause, strandings (Robson 1976, 1984; Rounsevell *et al.* 1981; Warneke 1983; McManus *et al.* 1984). These areas, often called "whale traps", have long sweeping gently shelving coasts ending in a section of steep coast, usually a headland or cliff, that juts out from the shelving coasts. Differences in echo-location reflections from the various coastal topographies increases the perception that the poor reflections from the shelving coastal topographies represent open water. Cetaceans swimming parallel with the coast would pick up strong echo-location returns from the steep coast, which if to seaward of their position, and give the impression that that direction is blocked. The poor signals received from the shelving coast might cause some cetaceans to mistakenly perceive that clear water lies ahead, thus they strand. This is a development of Dudok van Heel's theory, therefore it suffers from the same problems already outlined.

Coastal topographies can also influence strandings via the entrapment of the cetaceans by receding tides (Robson 1976, 1984; Geraci 1978; Wood 1979; Best 1982; Warneke 1983; McManus *et al.* 1984). Strandings on tidal flats have been reported from around Tasmania, mainly involving dolphins (Nicol 1987). One author (Wood 1979) has suggested that because of their obvious cause these events should not be considered as strandings.

Geomagnetic

Active strandings around the UK and along the eastern seaboard of the US tend to occur at sites near, or at, local minima in geomagnetic field intensity and where the contours of geomagnetic field intensity run perpendicular to, rather than parallel with, the coast (Klinowska 1985b, 1986a; Cornwell-Huston 1986; Kirschvink *et al.* 1986). These results led one researcher (Klinowska 1985b, 1986a) to suggest that active cetacean strandings are *exclusively* the result of navigational errors made while using an area's geomagnetic topography. There is extensive evidence for the use of geomagnetic topography as an orientation aid in the organisms other than cetaceans (Walcott *et al.* 1979; Ryan 1980; Walker 1981, 1984; Beason and Nichols 1984; Gould 1985; Beason 1986; Klinowska 1986c; Walcott 1986; Walker *et al.* 1986).

The major problems with this hypothesis are the lack of an anatomical feature for detecting the geomagnetic field (Zoeger *et al.* 1981; Bauer *et al.* 1985; Kirschvink and Walker 1986) and cetaceans are unlikely to rely on a single source for their orientation information (Norris 1967; Locker and Brown 1981; Gaskin 1982). In addition, correlations between geomagnetic topography and active stranding sites do not in themselves provide proof of causal relationships between them (Bauer *et al.* 1985; Kirschvink *et al.* 1986).

Periodic, but erratic, disturbance of the geomagnetic field have been suggested as a possible cause of active strandings. The disturbances are due to fluctuations in the magnetosphere, called magnetic storms and sub-storms (Klinowska 1986a, 1986b). Klinowska discovered that active cetacean strandings around the UK were often preceded by a magnetic storm. It was the timing of the magnetic storms rather than their intensity that was important, which suggested to Klinowska that magnetic storms may disrupt a time sense rather than a map sense. If cetaceans lost their time sense, an important component of orientation, close to shore their chances of becoming disorientated, and subsequently strand, would increase.

Again, correlations do not prove causal relationships, therefore evidence from other sources, such as anatomical and behavioural studies of cetaceans and other species, are needed to support Klinowska's hypothesis.

Oceanographic Conditions

Oceanographic features such as currents, tides and waves have been suggested as causes of some cetacean strandings (Robson 1976, 1984; Mead 1979; Cordes 1981, 1982; Warneke 1983; McManus *et al.* 1984; Klinowska 1985a). Most authors agree that passive strandings result from transportation of dead animals to stranding sites by the combined effects of winds, currents and waves (Mead 1979; Cordes 1981, 1982; Warneke 1983; Klinowska 1985a). Sergeant (1979, 1982) went to the extent of comparing all stranded cetaceans to oceanographers' drift bottles, suggesting that the distribution of both along a coastline are only the result of oceanographic features.

Tides can trap animals on tidal flats (as noted above) or, in conjunction with coastal topography, generate complex and variable conditions, possibly beyond the experience of oceanic cetaceans (Robson 1976, 1984; Geraci 1978; Geraci and St Aubin 1979a; Cordes 1981, 1982; Warneke 1983; McManus *et al.* 1984; Barzdo 1985). Spring tides, due to their greater tidal ranges, have been suggested as particularly difficult times for cetaceans (Robson 1976, 1984; Geraci 1978; Geraci and St Aubin 1979a; Warneke 1983; McManus *et al.* 1984).

The ability of any cetacean to handle oceanographic conditions depends on the combination of their experience and health. Thus, when cetaceans enter unfamiliar habitats they may not be able to cope with the different oceanographic features they encounter (Dudok van Heel 1962, 1966; Sheldrick 1979; Warneke 1983; McManus *et al.* 1984). Animals in poor health, due to age, parasite infection, injuries, or starvation, are likely to be at greater risk than healthy cetaceans. Other oceanographic features have been proposed as causes of strandings, including irregularities in the circulation of shallow straits (McCann 1964; Warneke 1983), and complex tidal and wind currents that occur near river mouths or headlands (Stephenson 1975; Warneke 1983).

The patterns of local and oceanic currents have been suggested as the explanation of distributions of strandings and species compositions for several regions, including Spain (Casinos and Vericad 1976), Florida (Moore 1953), the west coast of North America (Mitchell 1968), West Indies (Caldwell and Erdman 1963), and southeastern Australia (Guiler 1978; Warneke 1983; McManus *et al.* 1984). The usual distributions of some cetaceans have been inferred from their stranding patterns, in conjunction with local and oceanic circulations patterns. The distribution of several species of beaked whales (Moore 1958, 1963, 1966; Mitchell 1968) and the pygmy killer whale (*Feresa attenuata*) (Caldwell and Caldwell 1971) have been estimated by the above method. On the other hand, the strandings of some cetaceans, when the events are considered to be outside the species usual distribution, have often been explained by current patterns, as with several beaked whale strandings (Moore 1963, 1966; Guiler 1966) and a group of strandings of minke whales (Deraniyagala 1963).

Oceanographic features might also influence cetacean strandings indirectly via effects on the distribution of their prey, which could increase a cetacean's availability to strand, for example, by causing oceanic cetacean species to move inshore (Mead 1979). In general, the distribution of cetaceans is often related to oceanographic features such as boundary layers, fronts, upwellings and convergence zones as these areas generally have higher productivity (Omura and Nemato 1955; Uda and Dairokuro 1958; Hui 1979; Slijper 1979; Gaskin 1982). Such oceanographic features also occur in coastal waters where they are often associated with temporary concentrations of productivity which may attract cetaceans into these areas. Once inshore, the cetaceans can become susceptible to other factors that cause strandings.

HUMAN INDUCED

There are two broad groups of potential causes within this category; directly via harassment or injury of a cetacean (Geraci 1978; Wood 1979), and indirectly via the effects of pollution (Gaskin 1982; Munday 1985; Cowan *et al.* 1986). Several cetaceans have stranded with injuries that appeared to have been inflicted by humans or human-made objects. For example, the strandings of four Cuvier's beaked whales (*Ziphius cavirostris*) in the Caribbean (van Bree and Kristensen 1974) and a Stejneger's beaked whale (*Mesoplodon stejnegeri*) in California (Roest 1964) were suggested as being caused by nearby undersea explosions. The stranding of a Cuvier's beaked whale on the coast of Oregon was suggested as being due to a large injury on the animal's back, most likely the result of a collision with a ship's propeller (Roest *et al.* 1953).

Due to the high trophic position of toothed whales in marine food webs and their inability to metabolize or excrete pollutants quickly (notably heavy metals and pesticides) cetaceans are susceptible to bioaccumlation of these pollutants. In some regions of the world the levels of such substances have been found to be markedly higher in cetaceans than in other marine life or the surrounding seas (Robson 1976; Forrester *et al.* 1980; Gaskin 1982; Munday 1985; Carothers 1987). The effects of these pollutants upon cetaceans are not well understood but PCBs are believed to have reduced the reproductive success of seals in the Baltic Sea (Gaskin 1982). Recently, there have been two cases where strandings of cetaceans were possibly due to high levels of pollution. One case involved the stranding of beluga whales (*Delphinapterus leucas*) in the Saguenay River, Canada (Carothers 1987). The other case was the dramatic increase in the number of strandings of bottle-nosed dolphins along the eastern seaboard of the USA during the summer of 1987 (Holderness 1987). Cowan *et al.* (1986), in reviewing the pathology of stranded cetaceans on the Californian coast, suggested that the high levels of toxins in the animals may have a greater role in causing their strandings than parasites or other forms of diseases.

2.3.3.2 HEALTH OF THE ANIMALS

This category has received a lot of attention in both the popular and academic press (for example Robson 1976, 1984; Daily and Walker 1978; Geraci 1979; Warneke 1983; Barzdo 1985; Cowan *et al.* 1986). Many authors have suggested that most single stranders are unhealthy, suffering from a variety of illness and that they strand either directly or indirectly due to their ill health. Health problems can result from diseases, parasitic infections, starvation or injury. The role of stress in these factors is a matter of debate, with some authors suggesting that stress resulting from illness causes some strandings (Robson 1976, 1984; Cordes 1981, 1982), and others proposing that stress arising from dealing with unfamiliar environments, and unusual or difficult conditions combined with health problems may push animals beyond their physiological limits, leading to their subsequent stranding (Geraci 1979; Geraci and St Aubin 1979b). A central component of the debate relates to what are normal levels of infections for free-swimming and apparently healthy cetaceans (Geraci and St Aubin 1979b; Cowan *et al.* 1986).

DISEASE

This group includes the effects of bacteriological and viral infections, and physiological problems upon cetaceans. There are some strandings which are due to disease, such as the stranding of a common dolphin with hepatitis in Victoria, Australia (Dixon 1984). From the little that is known about cetaceans, however, most diseases are not life threatening on their own but if combined with high levels of stress, such as that associated with dealing with unusual circumstances, they may then become fatal (Geraci and St Aubin 1979b; Cowan *et al.* 1986).

PARASITES

A major source of illness in wild cetaceans, as presented in the scientific literature, is endoparasitic infections which have been described from stranded cetaceans around the world (Ridgway and Johnston 1968; Ridgway and Daily 1972; Colgrove and Migaki 1976; Robson 1976, 1984; Daily and Stroud 1978; Daily and Walker 1978; Daily *et al.* 1979; Geraci 1979; Geraci and St Aubin 1979b; Hall and Schimpff 1979; Ridgway 1979; Schimpff and Hall 1979; Stroud and Roffe 1979; Perrin and Powers 1980; Viale 1981; McColl and Obendorf 1982; Buck 1984; McManus *et al.* 1984; Cowan *et al.* 1986; Morimitsu *et al.* 1987). The main endoparasites are flukes, or trematodes (Phylum Platyhelminthes, Class Trematoda), and round worms, or nematodes (Phylum Nematoda), which have been found in all major organs and tissues. Most species of endoparasites appear to be host specific, even down to particular populations in some instances (Geraci and St Aubin 1979b; Cowan *et al.* 1986).

The level of parasitism varies between individuals, populations and species. The effects of different levels of parasitic infections are difficult to determine. In some cases the level of parasitism is so high that the function or health of organs or tissues are seriously reduced. For example, in some stranded cetaceans the kidneys were completely blocked by roundworms and the blubber was yellow implying kidney failure (Robson 1976, 1984). The effects of parasites upon their hosts can also be indirect via toxic by-products, either locally or remote from the infection, in which case it is difficult to relate the damage to the parasitic infection (Geraci and St Aubin 1979b; McManus *et al.* 1984).

The level of parasitism required to cause sufficient damage varies with the organ or tissue infected. High levels of parasitism within muscle tissue, while reducing the animal's overall condition, may not significantly reduce the animal's short term survival prospects. On the other hand, even very low levels of parasitism in vital organs, such as the brain or spinal cord could have major effects (Ridgway and Johnston 1968; Ridgway and Dailey 1972; Ridgway 1979; Cowan *et al.* 1986).

Many reports have mentioned parasitic infestations in the nasal passages and tympanic cavity of the middle ear, and have suggested that these parasites interfere with hearing reducing reception of echo-location signals, thereby increases the chances of stranding on shelving coasts (Robson 1976, 1984; Dailey and Walker 1978; Geraci 1978; Geraci and St Aubin 1979a; Cordes 1981, 1982; Parry *et al.* 1983; Warneke 1983; McManus *et al.* 1984; Morimitsu *et al.* 1987). Generally, even high levels of infestation have limited effects on surrounding tissues and are, therefore, unlikely to effect the animals' hearing (McManus *et al.* 1984; Cowan *et al.* 1986). In addition, Best (1982) reported that pelagic whalers, operating during last century, occasionally found very heavy parasitic infestations in the middle ears of otherwise healthy large male pilot whales. If the presence of parasites reduced the animals' hearing then it would have affected their ability to locate and capture prey, and therefore caused a decline in their overall health.

The presence of even a few parasites within the inner ear or the nerves leading to the brain (the eighth cranial nerve) would, however, have a marked effect on the hearing of cetaceans and may have contribute to their stranding (Dailey and Walker 1978; Cowan *et al.* 1986; Morimitsu *et al.* 1987). In a recent Japanese study of short-finned pilot (*Globicephala macrorhynchus*) and false killer whales (*Pseudorca crassidens*), collected from two herd strandings, parasites and tissue damage were found in and around the eighth nerve (Morimitsu *et al.* 1987)

While parasitic damage to the inner ear, related nerves and the brain may cause some strandings, their occurrence was low in stranded cetaceans from both the eastern (Geraci and St Aubin 1979b; Hall and Schimpff 1979; Schimpff and Hall 1979) and western coasts of the USA (Dailey and Walker 1978; Cowan *et al.* 1986). Buck (1984) and Cowan *et al.* (1986) have suggested that parasites are a minor cause of strandings. Cowan *et al.* reported that while some stranded animals had fresh parasitic infections many also showed signs of extensive old tissue damage caused by previous parasitic infections. These animals had recovered from their earlier infections, implying that parasitic infections, alone, are unlikely to be major causes of strandings.

An alternative hypothesis, proposes by Robson (1976, 1984), is that the influence of parasites is through irritation rather than the physical damage they cause and that irritation, or pain, particularly around the lower jaw and middle ear, affects the animals' behaviours to such an extent that they deliberately strand. Robson describes how animals display what he called "head-bashing" behaviour (where animals appear to hit their heads against rocks for some time prior to stranding). Upon examination, Robson usually found some degree of parasitic infection in the tissue beneath where the animals had been bashing themselves.

STARVATION

Another hypothesis is starvation, or malnutrition, with several factors being involved including old age, separation or abandonment of neonates, problems in capturing or eating prey, and lack of prey due to changes in oceanographic conditions or distribution of cetaceans (Robson 1976, 1984; Geraci 1978; Geraci and St Aubin 1979a; Cordes 1981, 1982; Best 1982; Warneke 1983; McManus *et al.* 1984; Barzdo 1985; Bossart *et al.* 1985). There are several examples of old animals and neonates coming ashore in very poor condition around Tasmania (Guiler 1978; McManus *et al.* 1984) and other areas of the world (Robson 1976, 1984; Mead 1979; Sheldrick 1979; Baker 1981a, 1983; Klinowska 1985a).

It is more difficult to demonstrate examples of the other potential causes of starvation, however, an example of malnutrition causing strandings, possibly due to the loss of prey, comes from the east coast of Florida where large numbers of pygmy sperm whales (*Kogia breviceps*) have stranded. Most of the animals examined had a heart complaint, thought to be due to malnutrition and the cause of the strandings (Bossart *et al.* 1985). To explain the malnutrition in the pygmy sperm whales the authors proposed that pygmy sperm whales occur in or near high productivity areas around the outside of warm Gulf Stream eddies off Florida and any whales associated with eddies that breakup lost their food supply. If some of these animals subsequently entered Florida coastal waters their reduced physical condition might decrease their abilities to cope and eventually some strand.

An interesting feature about stranded cetaceans is that they are often found to have little or no food in their stomachs. The lack of food, while not necessarily malnutrition, may indicate that the animals were hungry, which in turn, may have influenced the physical and mental abilities of the animals. An alternative explanation is that the stomach contents are vomited during the stranding or after death due to pressure from body weight and relaxation of stomach muscles.

INJURY

Another potential health-related cause of strandings is injury resulting from inter- and intra-specific encounters. Inter-specific encounters can be the result of attacks from predators, i.e. shark attacks (Robson 1976), or collisions (unintentional or otherwise). The latter is a possible explanation for the stranding of a male killer whale that had a severely damaged lower jaw, due to an embedded swordfish bill (Ross 1984). Intra-specific encounters have been reported between many toothed whales (Best 1979; Norris and Dohl 1980; Gaskin 1982) and, more recently, between baleen whales (Baker and Herman 1984; Kaufman and Forestell 1986; Silber 1986). An example of an intra-specific encounter which resulted in a stranding was outlined by Robson (1984). A male Arnoux's beaked whale (*Berardius arnouxi*) came ashore on Great Barrier Island, off the New Zealand east coast, following a fight with another whale (possibly another Arnoux's beaked whale) during which its lower jaw was broken.

POPULATION DENSITY

Sergeant (1979, 1982) proposed that stranding frequencies were related to the size of each species' population and that as populations increased, the number of strandings also increased. Sergeant suggested that the number of strandings was sufficient to regulate population levels. The population would continue to decline until strandings fell below replacements to the population, where upon the population would increase. The proposal, therefore, is that strandings are a density dependent mechanism for population control.

Sergeant made two main assumptions, namely that strandings are proportional to population levels and that they are a significant cause of mortality. However, Brown (1975) found no quantifiable relationship between cetacean strandings and sightings around the British Isles. Several authors (Best 1982; Dawson 1985) have questioned whether strandings are a significant cause of mortality since the number of strandings would have to be much greater than presently reported. An extreme situation is where nine species have only stranded once since records began in Tasmania (Nicol 1987). These low stranding rates imply that other causes of mortality, such as predation or disease, are likely to be more important than strandings (Mead 1979; Sheldrick 1979; Baker 1981a; Warneke 1983).

2.3.3.3 BEHAVIOUR

There are 12 hypotheses in the literature where some aspect of behaviour is the central component. Of these, three have some form of compulsion, or internal drive, for the animals to strand (termed "Compulsive Hypotheses"). Five hypotheses, collectively called "Errors of Judgement", deal with strandings in which animals come ashore either direct as a result of misjudgements or eventually due to errors made sometime prior to the strandings. A further hypothesis involves both an internal drive and errors of judgement. The final group of hypotheses deal with the question of what causes herd strandings or, more particularly, why such events involve more than one animal.

The interpretation of animal behaviour is one of the most difficult areas of biology which, in the case of cetacean strandings, is made more difficult by inaccurate or over-zealous reports. Another difficulty is the general lack of knowledge about cetacean behaviours. This situation has improved over recent years with increasing numbers of long-term studies being conducted on cetaceans in their normal environments (see Gaskin 1982; Evans 1987; Whitehead and Arnbom 1987). However, the state of knowledge about the behaviour and social structure of some species, particularly the beaked whales, is still very poor and unlikely to improve in the foreseeable future.

As a result of these problems the following reviews of behavioural hypotheses are simplistic and thus may inadvertently remove some of the potential complexity and variability of cetacean behaviour. It should always be remembered that cetaceans have a wide range of complex behavioural patterns with differing proportions of instinctive and learned origins. It is also unlikely that they will ever be fully understood.

COMPULSIVE HYPOTHESES

Of the three hypotheses included in this section, two suggest that cetaceans strand to prolong their lives. These hypotheses go further than suggesting that animals come inshore to rest in calm sheltered bays and inlets, rather they actively come ashore, often forcibly, and are driven by some compulsions. The third hypothesis claims that the animals are attempting to shorten their lives.

1) ***Fear of Drowning.*** This hypothesis, proposed by Robson (1976, 1984), suggests that since cetaceans are voluntary breathers they will fear drowning and this fear of drowning

causes ill or weak animals to seek the shore. The hypothesis is attempts to explain why some animals appear to deliberately come ashore.

There are several fundamental problems with this proposal; for instance evolutionary pressures would operate against such a strategy. Cetaceans are fully aquatic animals for which coming ashore is generally fatal therefore any behaviour that puts them in such a situation would appear to be maladaptive. At some stage in their evolution there must have been some selective pressure, either positive (to take advantage of an open niche) or negative (to escape land-based predation or competition) on ancestral cetaceans to leave the land completely. This pressure could have operated via the deaths of all animals that returned to shore.

The basic assumptions in Robson's notion are also questionable. Robson makes three main assumptions, namely that cetaceans *fear* drowning, that animals *actively seek* land so they can strand, and that the latter is the result of the former. These assumptions are based on Robson's interpretations of cetacean behaviour patterns. Firstly, he suggested that because cetaceans are voluntary breathers they must *fear* drowning, not just have a need or drive to surface and breathe. This implies that cetaceans are aware of the consequences of failing to breathe. Secondly, stranded animals *choose* to strand rather than drown, which also implies a human-like degree of perception. Thirdly, after choosing to strand cetaceans then seek land, again implying an ability to plan and follow through actions to a goal. If any of these assumptions are not valid then Robson's hypothesis must fail.

While it is not possible to say that fear of drowning is not a factor in some or all strandings, the supporting evidence from observations of strandings are open to other possible interpretations and the basic assumptions are untestable. Thus this hypothesis is not suitable to be used as part of any working hypothesis.

2) ***Instinctive Compulsion.*** This hypothesis concerns the behaviour of cetaceans when they actively seek land during periods of extreme stress. The seeking of land is, supposedly, driven by a deeply rooted instinct in which land represents safety, also called phyletic compulsion. Wood (1979) proposed this hypothesis in an attempt to explain several aspects of cetacean strandings not covered by earlier hypotheses, notably, the act of stranding can be anything from a slow deliberate swim to a rapid dash ashore, most stranded animals refuse to return to sea, and some stranded animals have been rehabilitated in captivity surviving for several months, even years, in apparent good health.

Wood suggested that during the evolution of cetaceans there was a period where ancestral cetaceans spent time at sea and on land. During this amphibious phase animals stressed at sea, such as attacked by marine predators or ill health, would seek safety on land, much as modern seals do today. Wood proposed that due to its very high survival value the biochemical basis for this "land seeking" behaviour would have been sited in the sub-cortical region of the brain, an area where "primitive" behaviours, such as feeding, sex and sleep, are based. Wood noted that during periods of intense stress animals generally revert to such "primitive" behaviours, therefore he suggested cetacean strandings were the result of animals, when under stress, reverting to the "primitive" behaviour of seeking safety ashore.

To explain how this behaviour continues to occur in cetaceans when the resulting strandings became fatal, Wood argued that this behaviour was linked, possibly genetically, to some "good" behaviour. Also, the significances of mortalities from strandings are low because the animals involved are often sick and they were not likely to survive whether or not they stranded, therefore, the selective pressure for the removal of this behaviour due to strandings would be low.

The major problem with this hypothesis, like the "fear of drowning" hypothesis, is that the seeking of safety ashore would have become maladaptive after cetaceans became fully aquatic (i.e. no longer amphibious). Geraci (1978) and Best (1982) questioned whether such a behaviour could be connected to a "good" behaviour considering the high degree of learning in cetacean. Wood admitted that it is not possible to test this hypothesis, therefore it can not form part of any working hypothesis.

3) ***Suicide.*** This hypothesis has often been mentioned by the popular media, although it is not supported in the scientific literature (Robson 1976, 1984; Geraci 1978; Brooks 1979; Wood 1979; Cordes 1981, 1982; Best 1982). It is based on the apparently deliberate way some cetaceans strand and their subsequent refusal to return to the sea. It has been suggested that the animals commit suicide to relieve pain caused by ill health or injury. Alternatively, Sergeant (1979, 1982) suggested that it was an act of altruistic self-euthanasia to reduce population density.

This hypothesis is not supported by the stranding record which includes many reports of cetaceans swimming away from strandings after refloating, both unassisted and assisted. These events indicate that some animals are willing, and able, to live after a stranding (Scott

1942; Anonymous 1963; Robson 1976, 1984; Guiler 1978; Rounsevell *et al.* 1981; McManus *et al.* 1984; Whiteside 1985, 1987). Information from behavioural studies do not indicate that cetaceans have the foreknowledge and perception that are part of the conscious act of suicide (Geraci 1978; Mawson 1978; Brooks 1979; Wood 1979; Gaskin 1982).

In general, Brooks sums up the position of most researchers on this hypothesis,

> "Mass suicide or other self-destructive behaviour would be truly aberrant ...and would not be expected to occur in nature." (Brooks 1979).

ERRORS OF JUDGEMENT

Errors of judgement include behaviours where healthy animals make mistake(s) in responding to aspects of their environment. Mistakes can be made while avoiding predators, chasing prey, navigating or during a period of social upheaval.

1) ***Predator Avoidance.*** Several authors (Geraci 1978; Cordes 1981, 1982; Best 1982) have reported that some cetacean strandings are the result of animals being chased ashore by predators. This hypothesis is not applicable to all strandings since predators are reported at only a few events (although they could have been present but not seen). There are examples where predators were seen in the area before, during or after a stranding, though, it was not possible to implicate the predators in the strandings.

Around Tasmania there have been four strandings where potential predators were sighted in the general locality before or while the event occurred. Killer whales were seen in Recherche Bay the day before the discovery of a stranded strap-toothed whale (*Mesoplodon layardi*) (Flynn 1922). The stranding of 15 common dolphins in Ralph's Bay was discovered the day after a pod of killer whales had been sighted at the bay's entrance (McManus *et al.* 1984). A southern right whale was reported to have been driven ashore on Tasmania's south coast by a large shark (Guiler 1978) while a large shark was seen following a Gray's beaked whale shortly before the whale came ashore on Bruny Island (Nicol 1987).

2) ***Chasing Prey.*** There are two aspects to this hypothesis. Firstly, some authors have suggested that animals may strand while they are chasing prey in shallow waters (Geraci 1978; Cordes 1981, 1982). This has been observed in killer whales (Lopez and Lopez 1985) and bottle-nosed dolphins (Hoyt 1984), although these examples involved the intentional short term

stranding of animals to capture seals or fish, respectively. Secondly, there is the possibility that oceanic cetaceans may be induced inshore to feed on locally plentiful coastal prey species then the cetaceans are unable to cope with the coastal conditions (Geraci 1978; Geraci and St Aubin 1979a; Cordes 1981, 1982; Best 1982). The occurrence of large numbers of potential prey in the immediate vicinity before, and during, some strandings has been reported (Hall *et al.* 1971; Geraci 1978).

Against this hypothesis, however, is the general trend that stranded cetaceans have little or no food in their stomachs, even if prey were plentiful (Geraci 1978; Geraci and St Aubin 1979a; Best 1982). To explain this lack of food it has been suggested that cetaceans either vomit their food when stressed, or continue to digest their prey after the stranding. There are only a few reports of cetaceans vomiting during a stranding, although stomach contents could have been expelled after death. On the other hand, some whales taken during whaling operations had full stomachs even though whaling must be very stressful for the harpooned whales (Geraci 1978; Best 1982). Against the continued digestion of their food is the general mammalian tendency to give their digestive tracts low priority during periods of stress, thereby slowing down, if not stopping, digestion.

Overall, it seems likely that the presence of prey species may induce both coastal and oceanic cetaceans into the nearshore area which, in conjunction with other factors, may occasionally result in some strandings.

3) ***Ancestral Pathways.*** This hypothesis proposes that cetaceans strand while following former migration routes now blocked (Scott 1942; Dudok van Heel 1962, 1966; Cordes 1981, 1982). Another version is that the cetaceans are following migration routes that were used by their pre-marine ancestors (Geraci 1978; Best 1982; Dawson 1985).

While some strandings do occur on geologically recent coasts previously open sea, such as sand spits and isthmuses, other events occur at the base of very old cliffs, sometimes older than the order of Cetacea itself (Geraci 1978; Cordes 1981, 1982; Best 1982). Also, the general nature of cetacean behaviour, with its high proportion of learned behaviour, does not favour this hypothesis, although it does not rule it out either (see section on Instinctive Compulsion).

4) ***Navigational Errors.*** This is principally concerned with behavioural errors or misjudgements made while navigating (see section 2.3.3.1). The mistakes could be in the

perception or interpretation of information from a range of sources, including geographic topography, echo-location signals, geomagnetic topography and oceanographic conditions. Additionally, some locations, due to their particular configurations, may be more prone to such errors.

The probability that a particular cetacean makes a navigational error will be influenced by several factors including experience and stress. Cetaceans encountering new complex conditions and unusual environmental events are more likely to have difficulties than animals that have already experienced and coped with the conditions. Stress is caused by a range of factors, including poor health. The combination of limited experience and high levels of stress may adversely affect the judgement of cetaceans.

5) ***Social Upheaval.*** Robson (1984) proposed social upheaval as another cause of navigational errors through the distraction of the animals away from the monitoring of their environment leading to difficult situations in such areas as inshore waters or enclosed bays. In addition, the stress associated with the social upheaval may affect the judgement of the cetaceans. Possible examples of social upheavals include changes in dominance structure or the driving of pubescent males from a school. Again, there is little evidence to support this hypothesis and it may, in fact, be difficult to obtain such evidence.

TACTILE STIMULATION

Mawson (1978) proposed that cetaceans enter shallow water to rub their skin on the sea floor. While the cetaceans are in the near-shore area some of them are stranded by sudden changes in the environment, such as in the oceanographic conditions (e.g. falling tides or sudden alterations in sea state or weather). Mawson developed this hypothesis to explain the apparent deliberate style of some events and the repeated stranding of animals being rescued. He argued that because cetaceans have a highly developed sympathetic nervous system they need tactile stimulation, in part, to relieve, or distract, themselves from stress. A major condition Mawson placed on his hypothesis was that most animals seeking tactile stimulation do not strand. Mawson stated that if his hypothesis were true then handling stranded cetaceans during rescue operations would cause these animals to attempt to remain on the beach since handling increasing the tactile stimulation. The animals would actively seek human contact rather than swim away.

The major problem with this hypothesis is that most species which commonly strand are oceanic and not regular users of coastal waters (Geraci 1978; Mead 1979; Sheldrick 1979; Baker 1981a, 1983; Warneke 1983). For example, sperm whales frequently strand (Guiler 1978; Baker 1981a, 1983; Warneke 1983; McManus *et al.* 1984) but they do not generally enter shallow waters, usually occurring in water deeper than 200m (Bannister 1968; Best 1979). On the other hand, southern right whales frequent the nearshore area, often resting on the bottom with their backs and blowholes are above the water (Gaskin 1982; Baker 1983). This species is a very rare strander (Baker 1983; Nicol 1987). It has been suggested that their very low stranding frequency is due to their familiarity with the coastal conditions (Guiler 1978; Baker 1983).

HERD STRANDINGS

Most authors postulate that single and herd strandings have different causes. In essence, single stranders are unhealthy, resulting in their strandings, while members of herd strandings are healthy (apart from the effects of the strandings) and some other factor(s) caused the stranding (Robson 1976, 1984; Geraci 1978; Geraci and St Aubin 1979a; Woods 1979; Cordes 1981, 1982; Best 1982; Warneke 1983). Not all researchers, however, accept that all single stranders are in poor health (Buck 1984; Cowan *et al.* 1986). Rather, many of the environmental and behavioural hypotheses are applicable to active single, as well as, herd strandings. Whether or not the causes of herd strandings are similar to those of single strandings there still remains the question; why did more than one animal, sometimes several hundred, strand at the same time? The following hypotheses represent the three most common explanations for herd strandings; the last hypothesis is currently the most widely accepted.

1) ***Mass Errors***. Where members of a herd simultaneously suffer the same problem, whether navigational error (Anonymous 1963), health (for instance parasites in the middle ear) (Geraci 1978; Wood 1979; Cordes 1981, 1982; Best 1982; Morimitsu *et al.* 1987) or mass suicide (see Brooks 1979). This hypothesis is not supported by the known health, behaviour and social structure of cetaceans commonly involved in herd strandings (Robson 1976, 1984; Geraci 1978, 1979; Geraci and St Aubin 1979a, 1979b; Best 1982; Warneke 1983; McManus *et al.* 1984; Barzdo 1985).

2) ***Follow the Leader***. In this hypothesis the leader of the school, or group, (generally assumed to be the largest male) is affected by a problem that causes it to strand. The problem

could be with the animal's health or an error of judgement. The group then instinctively follows their leader ashore (Geraci 1978; Wood 1979; Cordes 1981, 1982). This hypothesis seems to be based on the notion that cetacean social behaviours and structures are hierarchical and rigid. Recent behavioural studies have shown that many of the cetacean social structures are matriarchally based with no single fixed leader (Best 1979; Norris and Dohl 1980; Gaskin 1982; Whitehead and Arnbom 1987).

3) ***Social Cohesion.*** The common feature of the species that frequently herd strand are their highly developed social structures, ranging from stable family units through to highly gregarious species that occasionally form large aggregations of several hundred animals (Norris and Dohl 1980; Watson 1981; Gaskin 1982). On the other hand, species that only strand singly generally are solitary or form small family units. The behavioural basis of the highly social cetaceans are strong social bonds between members of a family, or social, unit. Examples of social cohesion can be seen in the co-operation between herd members during hunting. Connor and Norris (1982) have suggested that care-giving or epimeletic behaviour is one basis of social cohesion. They suggested that care-giving behaviour explains why herd strandings involving up to 300 animals have occurred as it is unlikely that these animals are members of one family or social unit.

Herd strandings begin when one or more animals get into difficulties (for any of the causes outlined above) and they begin to issue distress calls. Other members of the herd, or aggregation, respond and try to give assistance but they too become stranded, adding their distress calls to those of the first cetacean(s) ashore. This can continue until all the animals in the area are ashore, either through family associations that are increasingly distant from the original stranders or via displays of "care-giving" behaviour towards the stranded cetaceans.

Social cohesion also explains another important feature of herd strandings, the reluctance of animals to leave a stranding while animals remain alive on the beach. The animals ashore continue to issue their distress calls, thus the cause of the "herd" phase of the stranding is still operating and any "rescued" animals will return to the beach attempting to provide assistance (Robson 1976, 1984; Warneke 1984; McManus *et al.* 1984). A problem some authors (Geraci 1978; Wood 1979; Best 1982) have with this hypothesis is that some herd strandings have occurred over several kilometres of coast.

2.3.4 SUMMARY

In this section 22 hypotheses for cetacean strandings have been reviewed. The scope of these hypotheses range from those that deal with a limited set of circumstances, such as tidal entrapment or predator avoidance, to those that attempt to present a "grand" hypothesis, for example "fear of drowning" or suicide. Some of the limited hypotheses are applicable within their relevant circumstances, however, many of the "grand" hypotheses have questionable theoretical foundations and they are often untestable. It is not possible to say that these grand hypotheses are incorrect, but because they are untestable they can not be considered as part of the working hypothesis for this study.

The other important feature indicated by this review is that a stranding may have more than one cause and the effects of these causes can occur at a wide range of distances and times before the event. Causes that occur away from or prior to the event are difficult to study using information collected at the stranding event, no matter how detailed (Best 1982).

In general, it appears that most active strandings are the result of errors of judgement. These errors are induced or influenced by features of the physical environment, and the health and behaviour of the animals. It is outside the scope of this study to examine whether the effects are direct or via stress.

Considering the above information, the overall working hypothesis for this study is:

> *If cetacean strandings are influenced by aspects of the physical environment then the distribution and rate of strandings should vary in proportion to the distribution and intensity of aspects of the physical environment.*

Thus, areas with high numbers of strandings should have a feature, or combination of features, that induces cetaceans to strand there. At the same time, periods with increased stranding rates, both within and between years, should correlate with variations in the intensity or distribution of a feature, or combination of features, over time. Aspects of the physical environment suggested as possible influences on the location of cetacean strandings, include oceanographic conditions, and geographic and geomagnetic topographies. Features that may influence the rate of strandings include seasonal and annual variations in the weather, oceanographic conditions and geomagnetic disturbances.

CHAPTER 3 THE TASMANIAN CETACEAN STRANDING RECORD

3.1 INTRODUCTION

Data to test the working hypothesis (Chapter 2) comes from the accumulated cetacean stranding record of Tasmania. This chapter aims to present a summary of the Tasmanian cetacean stranding record.

In the development of the Tasmanian cetacean stranding record the first step is to identify all available strandings, checking and cross referencing to maximise the amount, and accuracy of information in the record. Then the record is examined for patterns indicating aspects, or features, worth detailed examinations. The next step is to consider the influence human activities on the record, since after a stranding has occurred it has to be discovered, reported and, finally, recorded.

3.2 THE TASMANIAN RECORD

3.2.1 INTRODUCTION

There is a considerable body of published information concerning cetacean strandings in Tasmania. Much of the record suffers from large variations in the scientific expertise of observers. To maximize both the quality and quantity of the stranding data, all records need to be re-examined to confirm their information and cross-checked to fill in gaps and remove errors were possible.

For the purposes of the data base the stranding record has been closed off at February 28 1986 as there was a need to finalise the data for subsequent analysis. A detailed description of the Tasmanian Cetacean Stranding Record can be found in Nicol (1987) where all known cetacean strandings, to February 28 1986 are presented.

3.2.1.1 EXPLANATION OF TERMS

TIME SCALE

A split year has been used in the graphs in this paper, rather than a calendar year, so that the summer months are grouped together. These months often have the greatest numbers of stranding reports and summer is also the period of maximum human activity on Tasmania's beaches. The split year begins on 1 July. The stranding records for each species were tested for seasonal patterns using the Chi-squared Goodness-of-fit Test (Snedecor and Cochran 1980). Species were either tested using monthly totals or clumped into three monthly totals. The actual grouping of the months depended on which combination produced the best result with respect to sample sizes in each cell.

DATE OF STRANDING

Strandings have two dates; when they occurred and when the event was discovered. In the present study unless otherwise stated, the date given is that of occurrence. It has been assumed that earlier authors followed a similar practice, although this may not have been the case.

COASTAL REGIONS

The Tasmanian coastline can be divided into four coastal regions on the basis of differences in oceanography, general topography and biogeography (Nicol 1985). These regions are (see Fig. 3.1): North Coast Region (NCR), the north coast from Cape Naturaliste to Cape Grim including the Bass Strait Islands; West Coast Region (WCR), the west and south coasts from Cape Grim to South East Cape; Storm Bay Region (SBR), from South East Cape to Cape Pillar, including Bruny Island; and East Coast Region (ECR), the east coast from Cape Pillar to Cape Naturaliste. These coastal regions will be used in subsequent analyses.

3.2.2 SUMMARY OF STRANDING RECORDS

The Tasmanian stranding record, to the end of February 1986, involved 22 species (Table 3.1). One of these, the blue whale, is yet to be positively identified as a Tasmanian strander, even though it may have stranded twice (Guiler 1978). Three other cetaceans have been reported from Tasmania, the pygmy sperm whale (*Kogia breviceps*), the dusky dolphin (*Lagenorhynchus obscurus*) and the hour-glass dolphin (*L. cruciger*), each is known only from a single undocumented museum specimen (in the case of the two dolphins it is the same skull!) that may or may not have come from stranded animals or even from Tasmania. Accordingly, these three species are not included as part of the stranding record here, even though earlier authors have done so (Pearson 1936; Davies 1963; Guiler 1978; McManus *et al.* 1984) (see Appendix II).

FIGURE 3.1

The principal geographic locations referred to in the text.

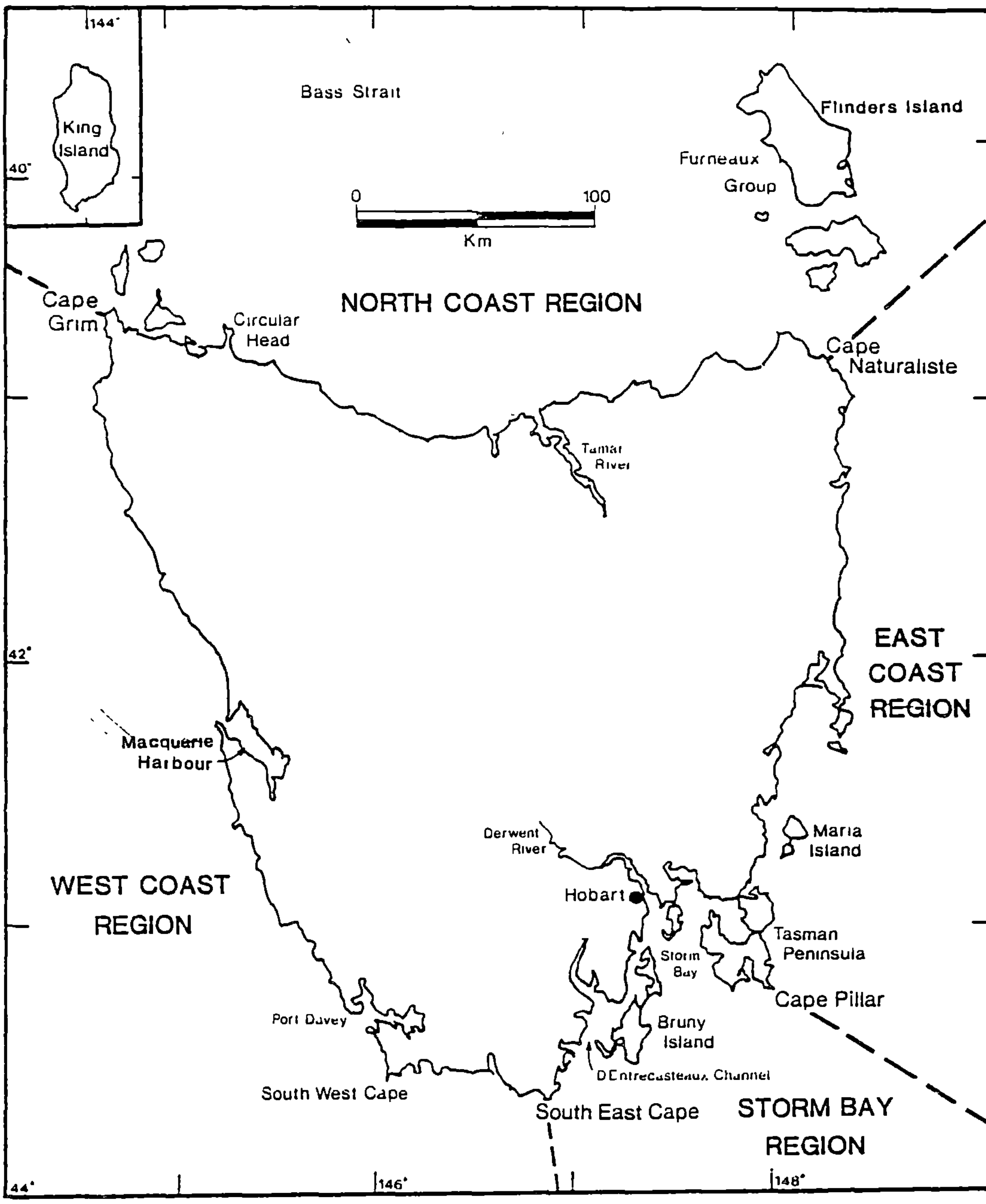


TABLE 3.1

TASMANIAN CETACEAN STRANDING RECORD TO 28 FEBRUARY 1986

CETACEAN SPECIES				NUMBERS OF STRANDINGS			
SUBORDER	**FAMILY**	**SPECIES**	**COMMON NAME**	**Single**	**Herd**	**Total**	**Animals**
ODONTOCETI (Toothed Whales)	Physeteridae (Sperm whales)	*Physeter macrocephalus*	Sperm whale	21 (1*)	10	31	210 +
	Delphinidae	*Delphinus delphis*	Common dolphin	14	10	24	218
	(Dolphins)	*Tursiops truncatus*	Bottle-nosed dolphin	18 (2*)	5	23	42
		Lissodelphis peronii	Southern right whale dolphin	1	0	1	1
		Globicephala melaena	Long finned pilot whale	10	20	30	1660 +
		G. macrorhynchus	Short-finned pilot whale	1	0	1	1
		Orcinus orca	Killer whale	1	1	2	3 +
		Pseudorca crassidens	False killer whale	4	9	13	548 +
			Unidentified Delphinids	0	4	4	245 +
	Ziphiidae	*Berardius arnouxi*	Arnoux's beaked whale	1	0	1	1
	(Beaked whales)	*Hyperoodon planifrons*	Southern bottlenose whale	1	0	1	1
		Mesoplodon densirostris	Densebeaked whale	1	0	1	1
		M. grayi	Gray's beaked whale	9	0	9	9
		M. hectori	Hector's beaked whale	1	0	1	1
		M. layardi	Strap-toothed whale	10	1	11	13
		Ziphius cavirostris	Cuvier's beaked whale	10	0	10	10

TABLE 3.1 CONTINUED

CETACEAN SPECIES				NUMBERS OF STRANDINGS			
SUBORDER	FAMILY	SPECIES	COMMON NAME	Single	Herd	Total	Animals
Mysticeti	Balaenidae	*Eubalaena australis*	Southern right whale	3	0	3	3
(Baleen Whales)	(Right whales)	*Caperea marginata*	Pygmy right whale	32 (1*)	0	32	33
	Balaenopteridae	*Balaenoptera acutorostrata*	Minke whale	4	0	4	4
	(Rorqual whales)	*B. borealis*	Sei whale	1	0	1	1
		B. musculus	Blue whale	1	0	1	1
		B. physalus	Fin whale	1	0	1	1
		Megaptera novaeangliae	Humpback whale	3	0	3	3
	Unidentified Large Cetaceans			4	1	5	7
TOTALS				152 (4*)	61	213	3017 +

NOTES:

* Number of strandings involving mother-calf pairs

\+ Numbers of cetaceans involved in some of these events are estimates only.

The 22 species have stranded around Tasmania on 213 occasions, with 152 single strandings (including four mother-calf pairs) and 61 herd strandings (two or more animals other than mother-calf pairs). All 22 species have stranded singly, with three species (a balaenid, a physeterid, and a delphinid, twice) having stranded in mother-calf pairs. Seven species, a ziphiid, a physeterid and five delphinids, have herd stranded, involving at least 2916 animals. The total number of stranded animals is around 3017. There has been a significant change to the Tasmanian Cetacean Stranding Record since Nicol (1987); the identity of a whale that stranding at Tatlow's Beach, near Stanley in 1947 (Guiler 1967) has been changed from an Andrew's Beaked Whale (*Mesoplodon bowdoini*) to a Gray's Beaked Whale (*M. grayi*) by Dr Ross (Warneke, personal communication 1986).

3.2.3 SPECIES BY SPECIES REVIEW

3.2.3.1 TOOTHED WHALES (ODONTOCETI)

Fifteen species from three families, sperm whales (Physeteridae), dolphins (Delphinidae) and beaked whales (Ziphiidae), have been reported from strandings around Tasmania (Table 3.1).

SPERM WHALES (FAMILY PHYSETERIDAE)

This family has two genera, a monospecific genus containing the sperm whale and a genus which contains, the pygmy sperm and dwarf sperm whales (*Kogia simus*). Only the sperm whale has been confirmed as occurring around Tasmania (Table 3.1) (see Appendix II).

Sperm Whales (*Physeter macrocephalus* Linnaeus, 1758) (Figs 3.2 & 3.3)

Sperm whale strandings represent 14.6% of all events and 6.9% of all animals stranded. There have been 10 herd strandings with a mean of 18.8 whales (standard error ± 6.1, range of 2-58) and 21 single strandings (including one mother-calf pair). Of the 31 events 13 could be classified as active events and 2 as passive strandings. The distribution of sperm whale strandings is displayed in Figure 3.2. Most strandings occurred from January to March ($0.05>P(\chi^2 = 9.79)>0.01$, df = 3). There are insufficient data to test the frequencies of single or herd strandings separately. The sexes of animals involved in seven herd strandings were recorded, two were bachelor herds (i.e. all males) and five were nursery herds (mixtures of sexes and ages).

Guiler (1978) and McManus *et al.* (1984) suggested that the combinations of complex oceanographic conditions and coastal topography off Tasmania's north west coast were major contributing factors in sperm whale strandings in that area. The Furneaux Group and north eastern Tasmania may cause similar problems for sperm whales on the eastern side of Bass Strait. In general, sperm whales are not usually found in water that is less than 200m deep (Bannister 1968; Best 1979; Gaskin 1982).

DOLPHINS (FAMILY DELPHINIDAE)

Seven of the 31 species in this family have been reported as stranding around Tasmania (Table 3.1) although three other species may occur off Tasmania's coasts (Section 3.3.5).

Common Dolphin (*Delphinus delphis* Linnaeus, 1758) (Figs 3.4 & 3.5)

Common dolphin strandings account for 11.3% of all events and 7.2% of animals in the record. There have been 10 herd stranding events with a mean of 20.4 dolphins (standard error ± 10.3, range of 2-109) and 14 single events. Twelve events could be classified as active while another 3 events were known to be passive strandings.

Figure 3.4 displays the location of common dolphin strandings. Most strandings are from the lower east coast and Storm Bay area. Figure 3.5 shows the number of strandings per month for common dolphins which a marked peak from December to February ($0.05>P(\chi^2 = 11)>0.01$, df = 3). No herd strandings have been reported from April to August.

Gaskin (1968, 1982) reported that the 14°C surface isotherm appears to form the southern limit for common dolphins off eastern New Zealand. Off Tasmania, the average sea surface temperatures range in winter from <11°C in the south to >13°C in the north east (Thomas and Shepherd 1982). Guiler (1978), reported that common dolphins mainly occur in the D'Entrecasteaux Channel area (Storm Bay Region) during winter, plus Nicol (1987) reported that common dolphins have stranded in southern Tasmania during winter, thus the 14°C isotherm may not be a limiting factor for common dolphins around Tasmania.

Bottle-nosed Dolphin (*Tursiops truncatus* (Montagu, 1821)) (Figs 3.6 & 3.7)

Strandings of bottle-nosed dolphins represent 10.8% of events and 1.4% of animals stranded. There have been 6 herd stranding events with a mean of 4.4 dolphins (standard error ± 1.5, a range of 2-10) and 18 single events (including 2 mother-calf pairs). Nine strandings could be classified as active events while the remainder were unclassified.

The distribution of bottle-nosed dolphin strandings is shown in Figure 3.6. It is very similar to that of common dolphins (Fig. 3.4) but there are some events from the Circular Head area. The number of bottle-nosed dolphin strandings per month, in Figure 3.7, shows variation, but there is no sign of seasonality ($P(\chi^2 = 4.909)>0.10$, df = 3).

Southern Right Whale Dolphin (*Lissodelphis peronii* (Lacépède, 1804)) (Fig. 3.8)

This species' stranding record consists of a single beach-washed skull (SBR) (Baker 1981c).

Long-finned Pilot Whale (*Globicephala melaena* (Traill, 1809) (Figs 3.9 & 3.10)

Long-finned pilot whale strandings account for 14.1% of events and 55.0% of animals. Twenty herd stranding events have been record, with a mean of 91.9 whales (standard error ± 20.6, a range 2-300), the remaining 10 strandings were singles. Twenty one events were reported as active strandings while only one event was known to be a passive stranding. Figure 3.9 shows the location of the long-finned pilot whales strandings around Tasmania. Events have been reported from along most coastlines.

The frequency of long-finned pilot whale strandings per month (Fig. 3.10) shows some seasonality, with more events reported in summer and early autumn ($0.05>P(\chi^2 = 10)>0.01$, df = 3). Strandings of pilot whales in New Zealand showed a similar pattern (Baker 1981a).

Short-finned Pilot Whale (*G. macrorhynchus* Gray, 1846) (Fig. 3.8)

There has been only one confirmed stranding of this species (Scott and Green 1975; Guiler 1978). This stranding is significant as it indicates that the identifications of long-finned pilot whales in some previous events might have been incorrect (Nicol 1987). A similar situation was discovered in New Zealand (Baker 1981a, 1983) and along the eastern seaboard of the USA (Mead 1979).

Killer Whale (*Orcinus orca* (Linnaeus, 1758)) (Fig. 3.8)

Killer whales have stranded twice, both active events but their familiarity with coastal areas may help explain their low stranding frequency (Baker 1983). Robson (1984) suggested that killer whales are able to remain upright when grounded, thus they are able to take advantage of incoming tides or waves. Killer whales off Argentina, which intentionally strand whilst chasing sea-lions, have little difficulty returning to deep-water (Lopez and Lopez 1985).

False Killer Whale (*Pseudorca crassidens* Owen, 1846) (Figs 3.11 & 3.12)

False killer whale strandings represent 6.1% of events and 18.2% of stranded animals. There were 9 herd strandings with a mean of 68 whales (standard error ± 16.5, a range of 21-170) and 4 single events. Nine of the 13 events are known to be active strandings.

The number of strandings per month for false killer whales (Fig. 3.12) was insufficient to test for any seasonality. This species has not strandings around Tasmania since 1976 suggests that Tasmania is outside the normal distribution of false killer whales (see Appendix II). They are regularly reported from around south eastern Australia (Wakefield 1967; Aitken 1971; Robinson 1984).

Unidentified Dolphins (Fig. 3.8)

There are four events for which species identities are unknown but evidence exists to indicate that they were delphinids. Two events reportedly involved dolphins, most likely common dolphins, (Scott 1942; Nicol 1987). The two other events probably involved false killer or pilot whales (Guiler 1978; Nicol 1987). All four events were herd strandings therefore they are considered to be active strandings.

DOLPHIN SUMMARY

The seven delphinid species that have stranded around Tasmania can be divided into three broad groups according to their general distribution:

1. regular coastal users - common and bottle-nosed dolphins, and killer whales;
2. oceanic and common or regular visitors - long-finned pilot and false killer whale, and
3. oceanic and infrequent visitors - short-finned pilot whale and southern right whale dolphin.

The stranding distributions of the seven species are similar. For two species, common dolphins and long-finned pilot whales strandings significantly peaked during summer, which may indicate increased in inshore activities for these species. The other species either showed no seasonal patterns or had insufficient data to be tested.

Figure 3.2

Distribution of Sperm Whale Strandings.

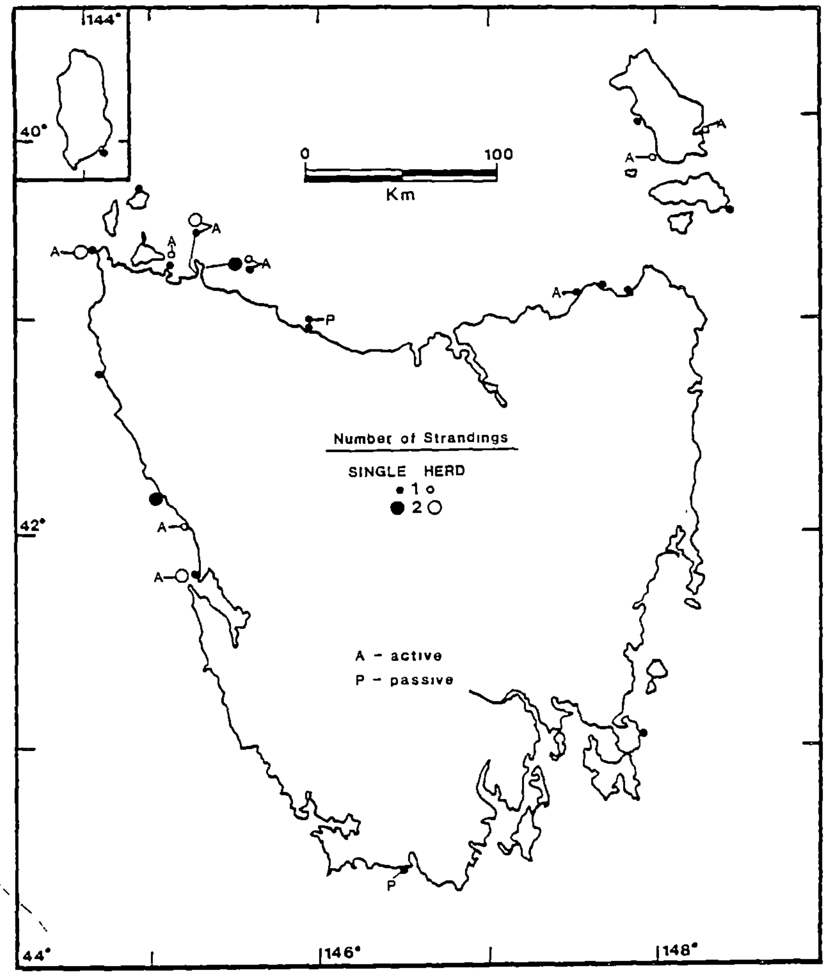


Figure 3.3

Number of Sperm Whale Strandings reported per month

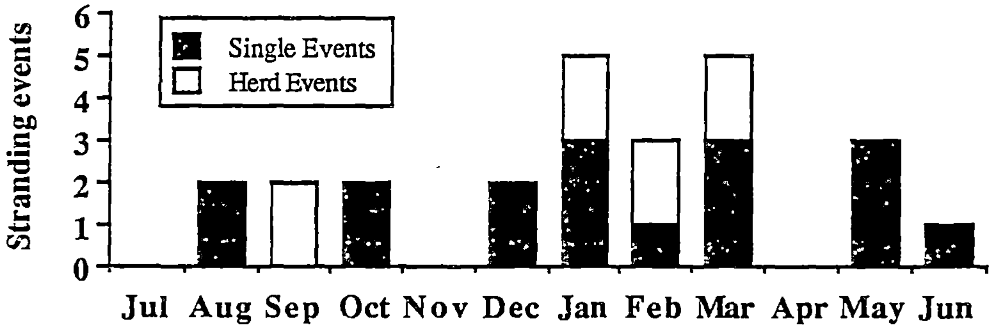


Figure 3.4

Distribution of Common Dolphin Strandings.

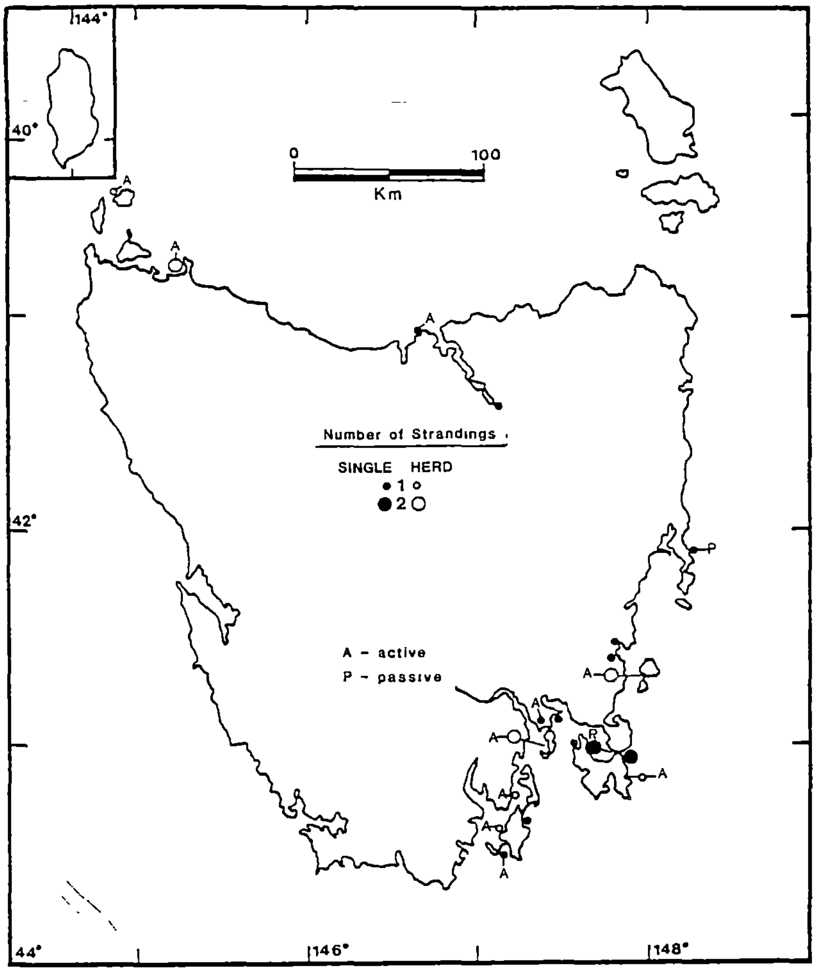


Figure 3.5

Number of Common Dolphin Strandings reported per month

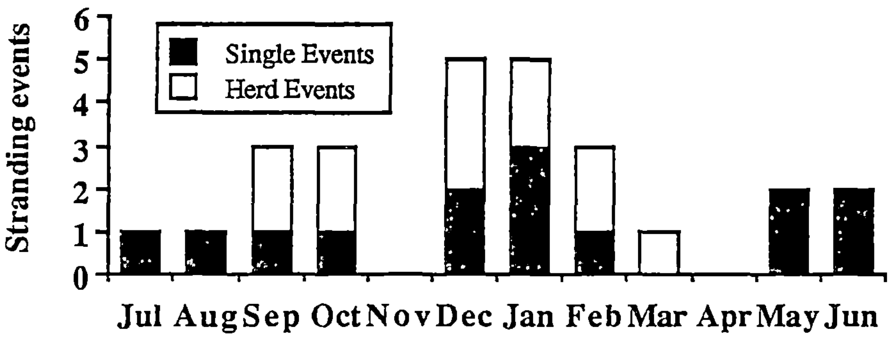


Figure 3.6

Distribution of Bottle-nosed Dolphin Strandings.

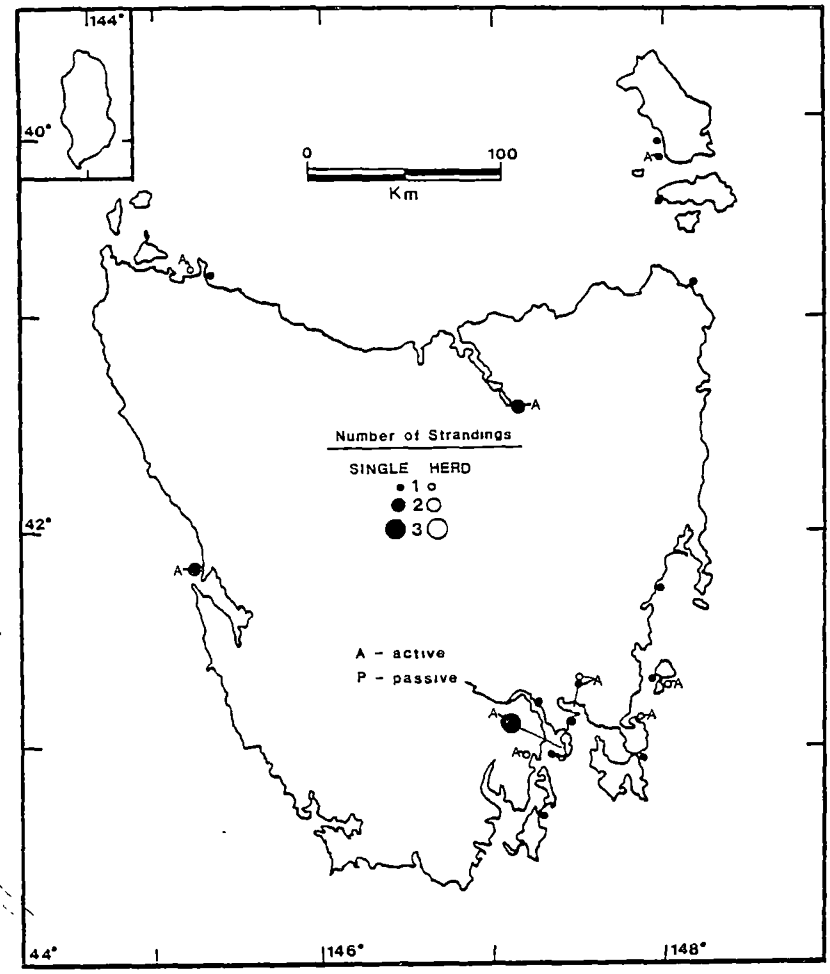


Figure 3.7

Number of Bottle-nosed Dolphin Strandings reported per month

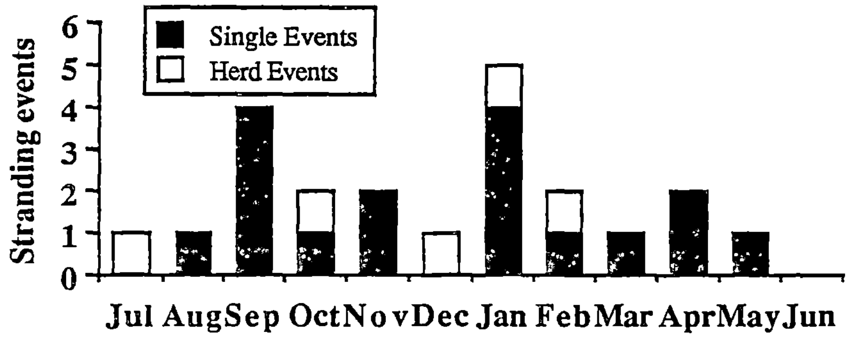


Figure 3.8

Distribution of unidentified dolphins and large cetacean strandings.

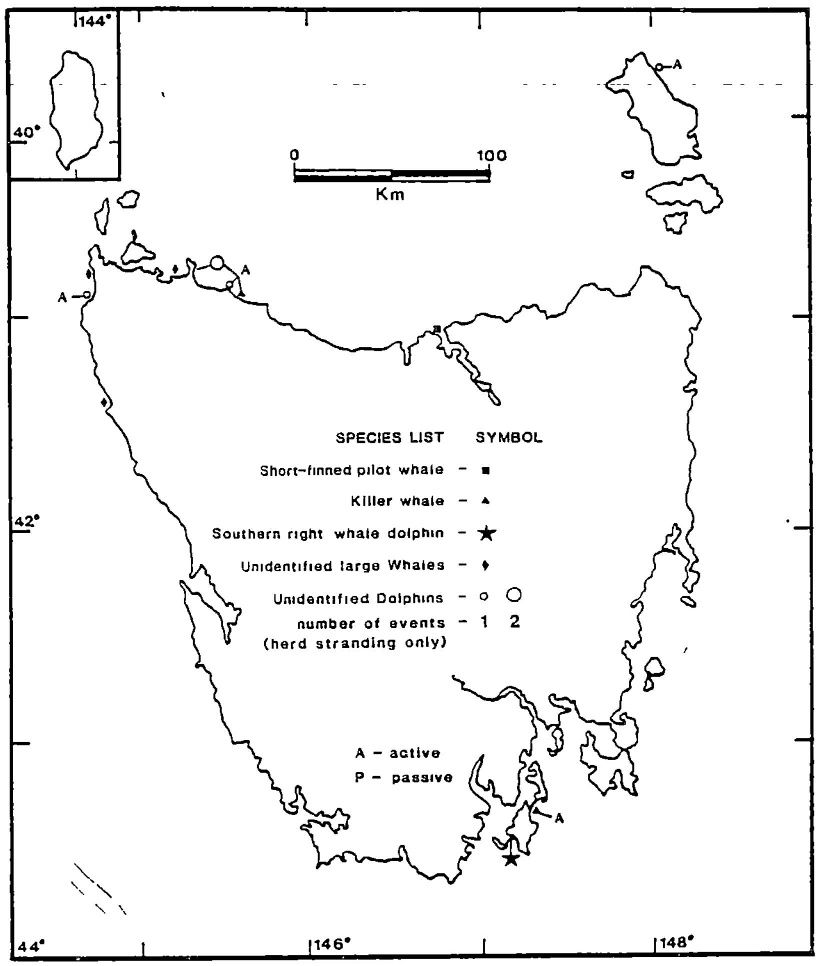


Figure 3.9

Distribution of Long-finned Pilot Whale Strandings.

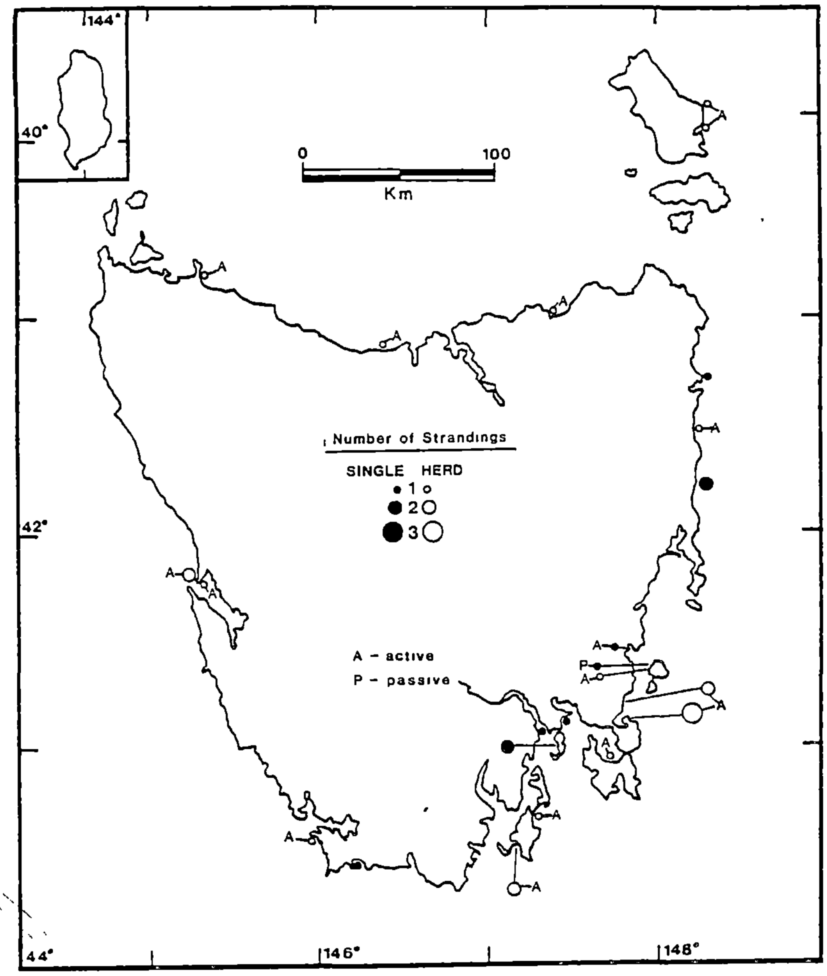


Figure 3.10

Number of Long-finned Pilot Whale Strandings reported per month

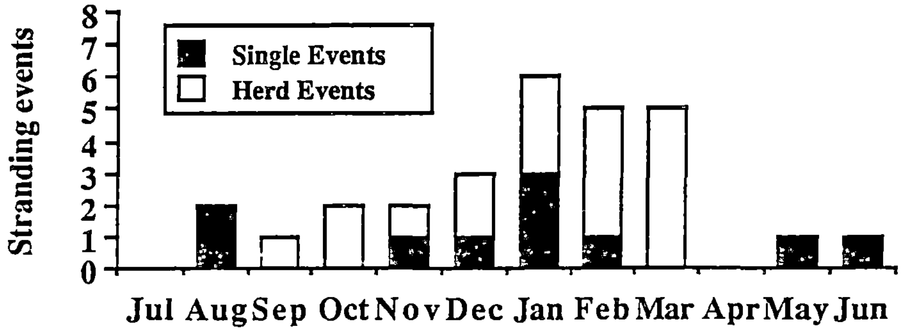


Figure 3.11

Distribution of False Killer Whale Strandings.

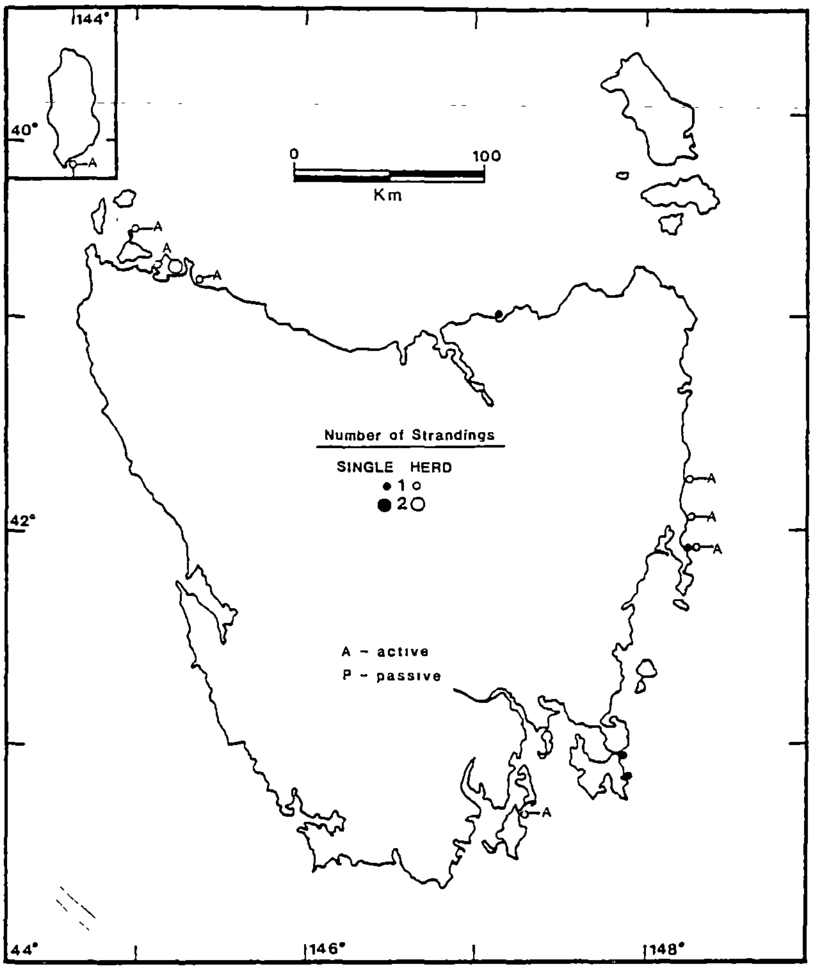


Figure 3.12

Number of False Killer Whale Strandings reported per month

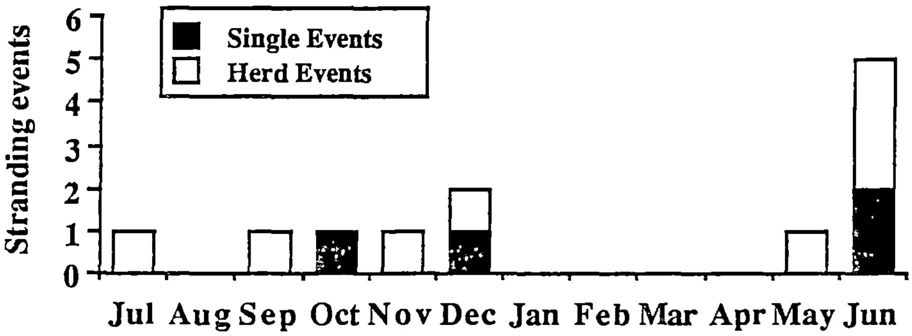


Figure 3.13

Distribution of Beaked Whale Strandings, except for Gray's Beaked Whale, Strap-toothed Whale and Cuvier's Beaked Whale.

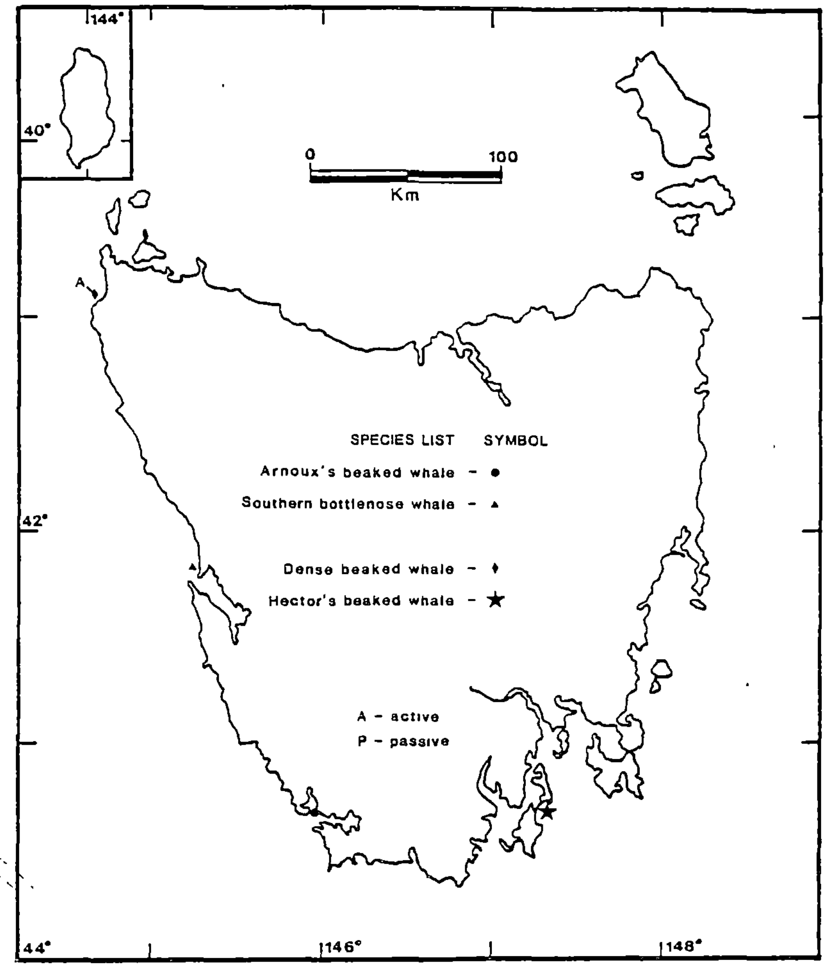


Figure 3.14

Number of Beaked Whale Strandings reported per month

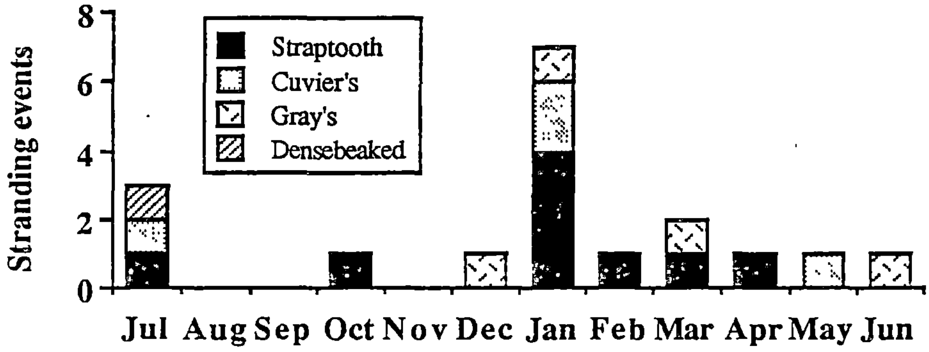


Figure 3.15

Distribution of Gray's Beaked Whale Strandings.

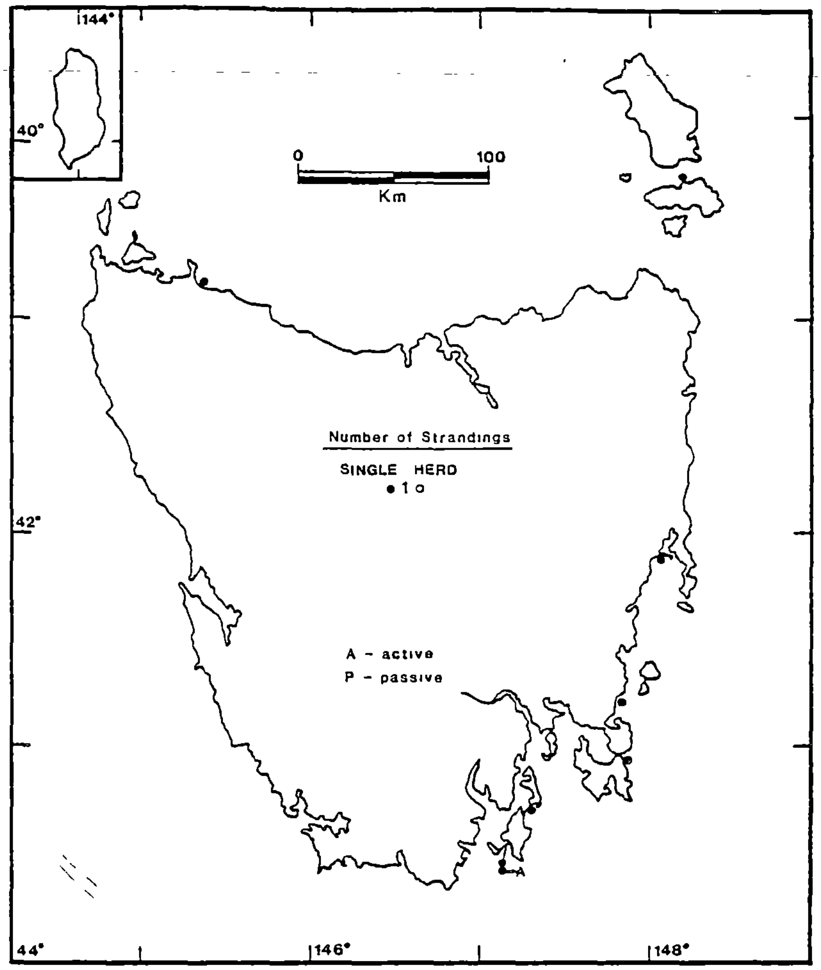


Figure 3.16

Distribution of Strap-toothed Whale Strandings.

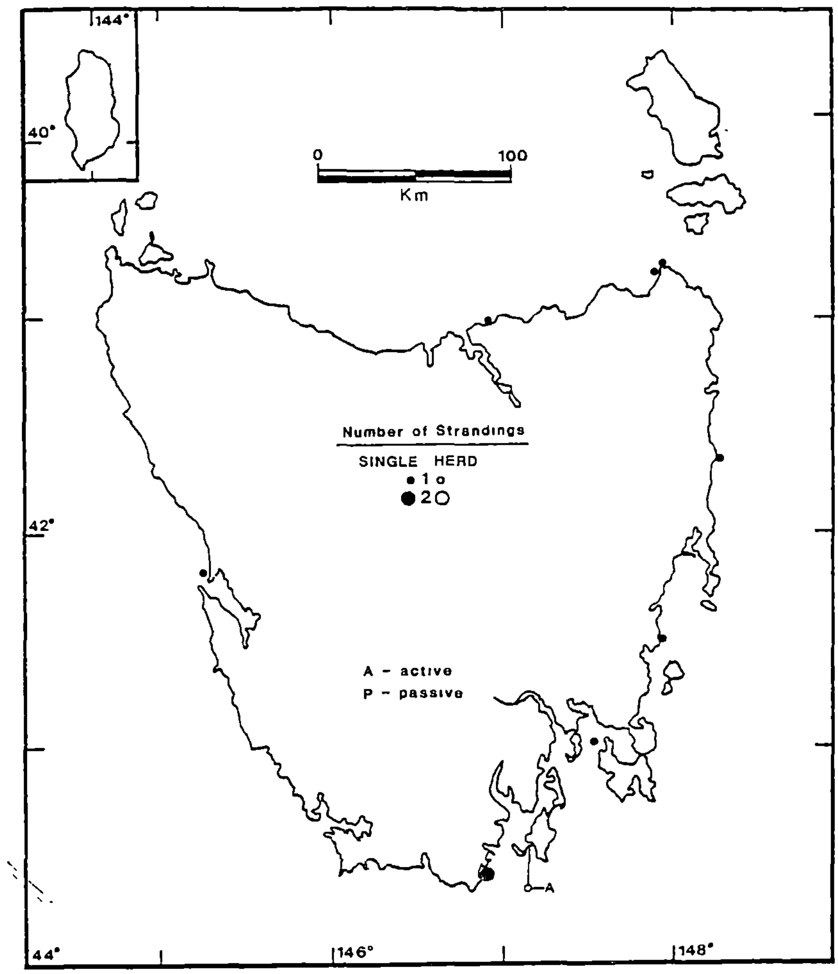


Figure 3.17

Distribution of Cuvier's Beaked Whale Strandings.

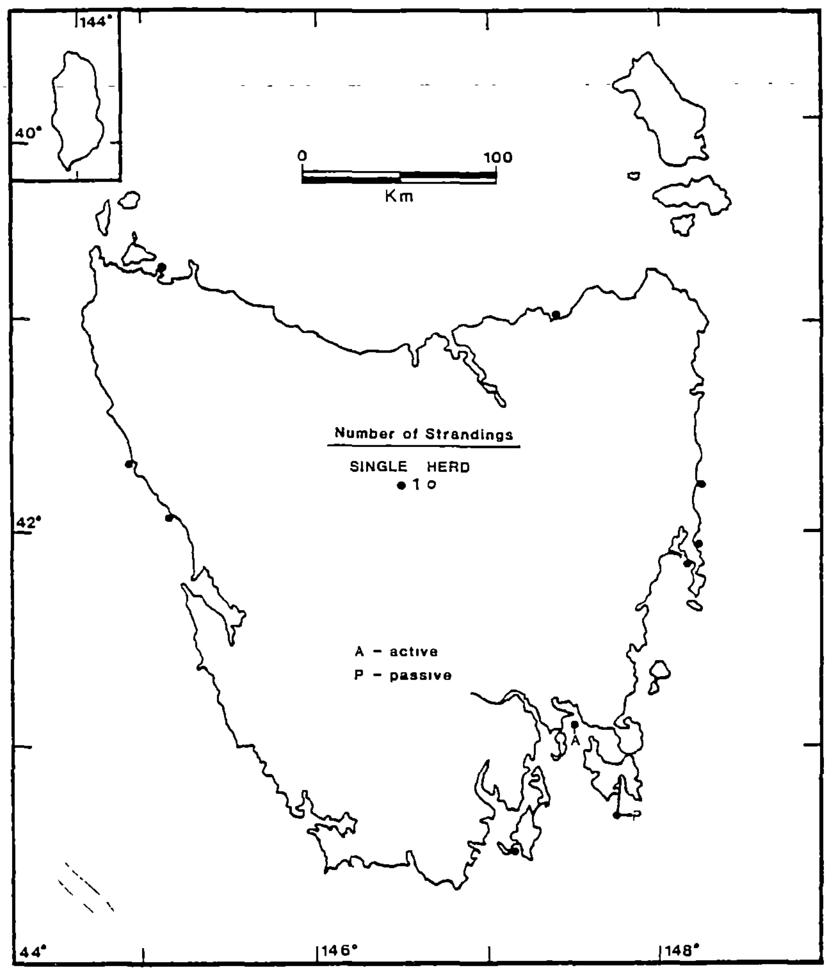


Figure 3.18

Distribution of Baleen Whale Strandings, except for the Pygmy Right Whale.

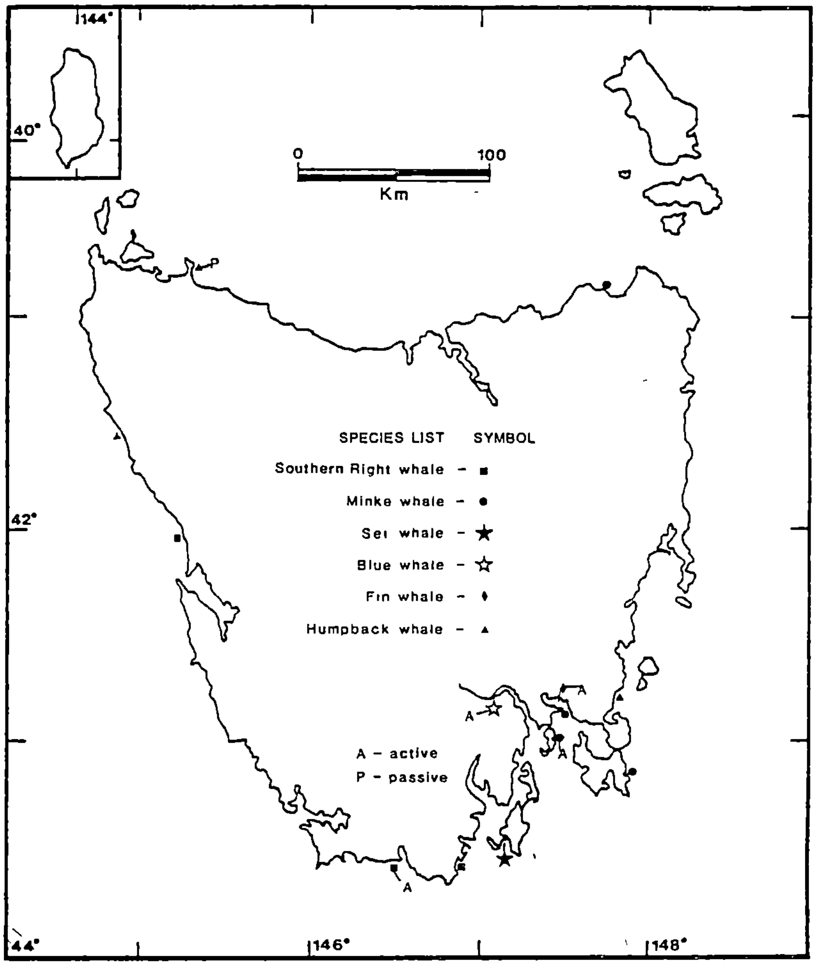


Figure 3.19

Number of Baleen Whales Strandings reported per month, except for the Pygmy Right Whale

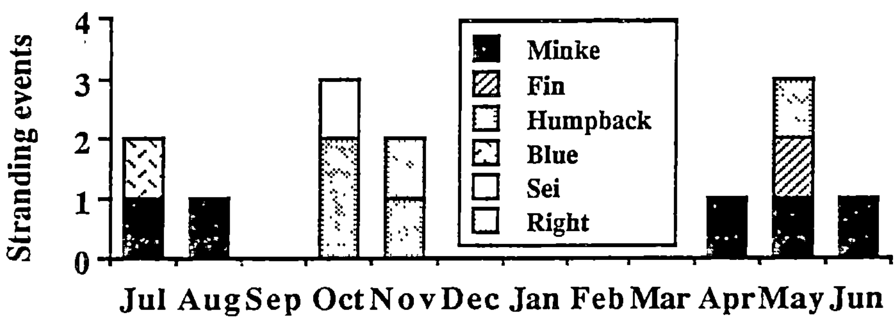


Figure 3.20

Distribution of Pygmy Right Whale Strandings.

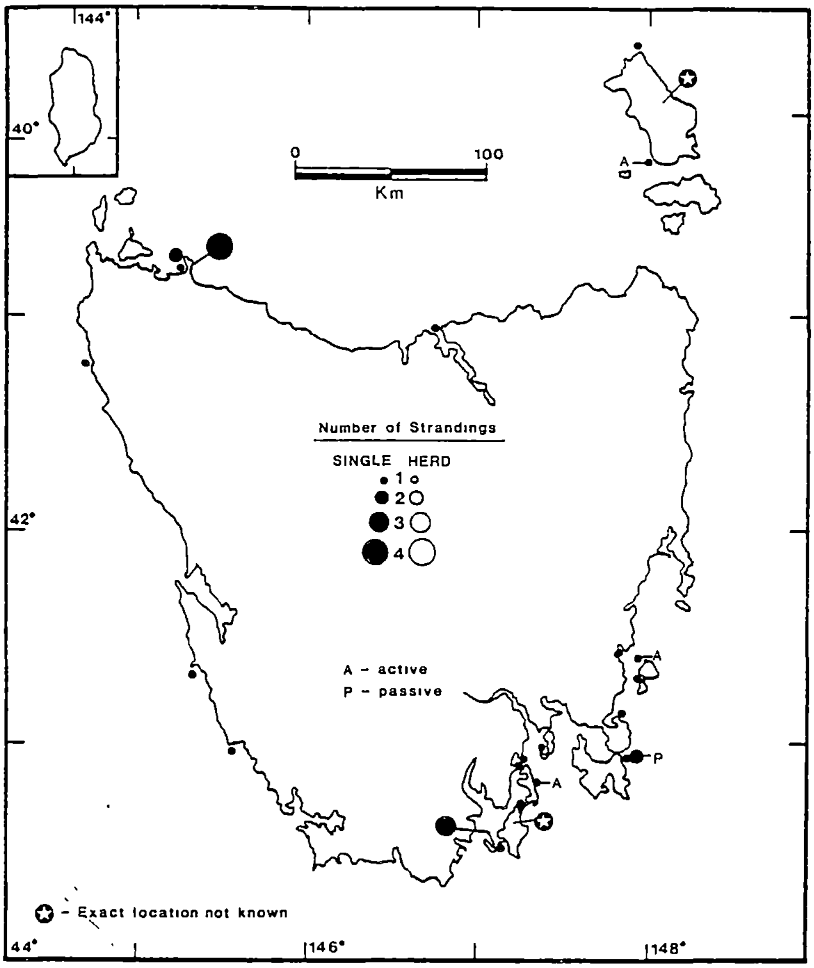
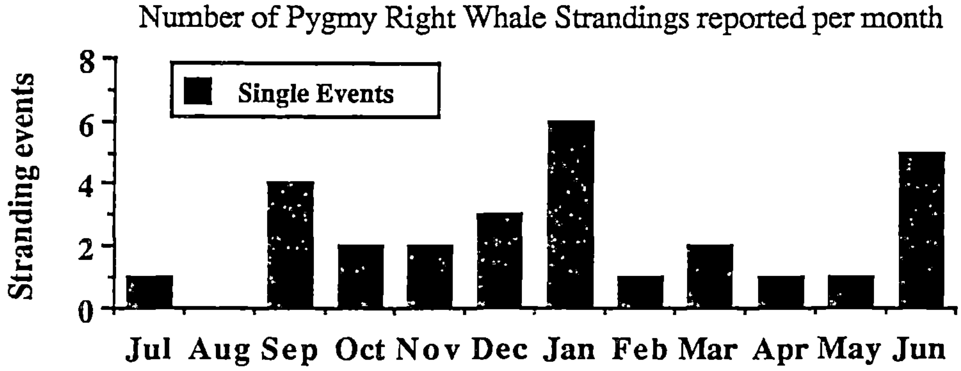


Figure 3.21

Number of Pygmy Right Whale Strandings reported per month



BEAKED WHALES (FAMILY ZIPHIIDAE)

Seven species (from four genera) have been recorded as stranding around Tasmania (Table 3.1). Beaked whales usually are oceanic and basically solitary, rarely forming groups larger than five animals (Watson 1981; Gaskin 1971, 1982; Norris and Dohl 1980; Baker 1983).

Arnoux's Beaked Whale (*Berardius arnouxi* Duvernoy, 1851) (Fig. 3.13)

This species is known from a single weathered skull (Guiler 1978).

Southern Bottlenose Whale (*Hyperoodon planifrons* Flower, 1882) (Fig. 3.13)

Again, this species is recorded from a single beach weathered skull (Davis and Guiler 1984; McManus *et al.* 1984).

Densebeaked Whale (*Mesoplodon densirostris* (de Blainville)) (Figs 3.13 & 3.14)

The single stranding of this involve the discovery of a fresh carcass, possibly the small whale seen in the area prior to the stranding (Guiler 1966, 1978).

Guiler (1966) suggested that this whale had come from the Indian Ocean. The Leeuwin Current, which occasionally flows from Western Australian east across the Great Australian Bight then south past the west coast of Tasmania (Maxwell and Cresswell 1981; Thomson and Carpenter 1985; Rochford 1986) might have transported this specimen to north western Tasmania.

Gray's Beaked Whale (*M. grayi* von Haast, 1876) (Figs 3.14 & 3.15)

Strandings of Gray's beaked whale totalled 4.2% of events and 0.3% of animals, and included only 1 known active stranding. Most strandings occurred on the eastern side of Tasmania (Fig. 3.15). In New Zealand, most strandings also occurred along the eastern coastline (Baker 1981a). Strandings of Gray's beaked whale have not been reported from July to November (Fig. 3.14), however, insufficient data exists to test this observation. It is worth noting, that in New Zealand a similar pattern has been reported (Baker 1981a).

Hector's Beaked Whale (*M. hectori* (Gray, 1871)) (Figs 3.13 & 3.14)

Hector's beaked whale is one of the rarest beaked whales. Its only stranding in Tasmania was of a carcass extensively eaten by sharks (Guiler 1967, 1978), therefore it can be classified as a passive event.

Strap-toothed Whale (*M. layardi* (Gray, 1865)) (Figs 3.14 & 3.16)

Strap-toothed whale strandings represent 5.2% of all events and 0.43% of animals in the Tasmania record. There was a single herd stranding involving 3 whales, which was also the only known active stranding. The distribution of strap-toothed whale strandings is predominantly eastern (Fig. 3.16). Six events occurred over the summer (Fig. 3.14), however, there is inadequate data to test whether or not this effect is due to chance.

Cuvier's Beaked Whale (*Ziphius cavirostris* (G. Cuvier, 1823)) (Figs 3.14 & 3.17)

Cuvier's beaked whale was the first beaked whale described from Tasmania (Scott and Lord 1920a, 1920b). The species represents 4.7% of events and 0.33% of animals. One event could be classified as active and one as a passive stranding, with most strandings occurring along the eastern coast of Tasmania (Fig. 3.17). The lack of strandings between August and December may indicate some seasonality (Fig. 3.14), however, there was insufficient data to test this observation. In New Zealand no seasonal pattern was apparent (Baker 1981a).

BEAKED WHALE SUMMARY

The major problems encountered when examining beaked whale strandings are the small sample sizes for each species, and the group as a whole, and the low proportion of events with determined health status. There are, however, some features of the beaked whale stranding record that can be commented on. The distributions of beaked whale strandings (Figs 3.12, 3.14, 3.15 and 3.16) show that 23 of the 30 events occurred in the eastern half of the state, 18 on the east coast or in Storm Bay. This could be due to greater human activity in these areas. The frequency of beaked whale strandings per month (Fig. 3.13) indicates a possible peak in January, but there are too few events for this observation to be tested.

Gaskin (1971) reported a strong correlation between beaked whale sightings and the 15°C surface isotherm. Beaked whales were more common between 40-45°S than 34-39°S or further south off southeastern New Zealand. Gaskin related this distribution to the Subtropical (or Subantarctic) Convergence Zone, an area where subtropical and subantarctic waters mix, increasing the level of biological activity. It is worth noting that the northern edge of the Subtropical Convergence Zone occasionally occurs off south eastern Tasmania (Harris *et al.* 1987, 1988).

3.2.3.2 BALEEN WHALES (MYSTICETI)

Seven species (in two families), have been reported from strandings around Tasmania (Table 3.1).

RIGHT WHALES (FAMILY BALAENIDAE)

In this family there are two species that occur in the southern hemisphere (Baker 1983), the southern right whale and the pygmy right whale and both have stranded around Tasmania.

Southern Right Whale (*Eubalaena australis* Desmoulins 1822) (Figs 3.18 & 3.19)

Only three single events have been recorded, of which one was known to be active (Guiler 1978). The familiarity of this species with the oceanographic conditions prevailing in coastal waters is the most likely reason for its low number of strandings (Guiler 1978; Baker 1981a, 1983). Southern right whales migrate between summer feeding grounds in subantarctic and antarctic waters and winter breeding grounds in coastal waters off southern Australia (Gaskin 1982; Dawbin 1983). The strandings of southern right whales around Tasmania in April and November are likely to represent the extremes of their occurrence in Tasmanian waters.

Pygmy Right Whale (*Caperea marginata* (Gray, 1846)) (Figs 3.20 & 3.21)

Pygmy right whale strandings account for 15.1% of events and 1.1% of animals. One event involved a mother-calf pair while the remainder were single strandings. Only seven events could be classified, 4 active and 3 passive strandings. Figure 3.20 shows the distribution of pygmy right whale strandings. Two areas have high numbers of strandings, Circular Head on the north west coast, and the Storm Bay Region, both have areas of shoaling waters with extensive tidal flats. The frequency of pygmy right whales strandings per month (Fig. 3.21) shows that this whale strands throughout the year ($P(\chi^2 = 2.857) > 0.25$, df = 3).

RORQUAL WHALES (FAMILY BALAENOPTERIDAE)

Four species from the genus *Balaenoptera* and the species of the genus Megaptera have been reported as stranding around Tasmania.

Minke Whale (*Balaenoptera acutorostrata* Lacépède, 1804) (Figs 3.18 & 3.19)

Four strandings are reported from the eastern half of Tasmania (Fig. 3.18). Three events involved newly born animals and all occurred during the winter (Fig. 3.19), this may indicate an inshore movement of minke whales during their breeding season, as proposed by Davis and Guiler (1957) and Guiler (1978).

Sei Whale (*B. borealis* Lesson, 1828) (Fig. 3.18)

A decomposing carcass was discovered at Cloudy Bay, Bruny Is. (SBR) (McManus *et al.* 1984).

Blue Whale (*B. musculus* (Linnaeus, 1758)) (Figs 3.18 & 3.19)

A stranding of a whale at New Norfolk, some 50km up the Derwent River (SBR) (Fig. 3.18), in 1825 (Crowther 1920; Lord and Scott 1924; Guiler 1978) is the earliest stranding in the Tasmanian record. The species identification is based on its size, since 27.3m is too large to be another species.

Fin Whale (*B. physalus* (Linnaeus, 1758)) (Figs 3.18 & 3.19)

A single active stranding is recorded for this species (Guiler 1978). The large whale stranded in Pittwater, a large enclosed area of tidal flats with a very narrow entrance.

Humpback Whale (*Megaptera novaeangliae* (Borowski, 1781)) (Figs 3.18 & 3.19)

There are three strandings of humpback whales in the Tasmanian record, including a passive stranding.

The waters off western Tasmania are not usually considered part of this species' migration routes (Dawbin 1983), but the two strandings on the west coast may indicate otherwise.

Baleen Whale Summary

Baleen whale strandings account for 21.1% of the total number of event, mainly due to pygmy right whale strandings (15% of the total). Pygmy right whales may stranded often because they may enter coastal waters to calve (Davies and Guiler 1957; Baker 1985). The other six species have low stranding frequencies because they are oceanic and rarely enter coastal waters, (minke, sei, blue and fin whales), they have experience of the nearshore environment (southern right and, to lesser extent, humpback whales), their population levels were drastically reduced by whaling (southern right, sei, blue, fin and humpback whales; see Gaskin 1982) or a combination of these factors.

Baleen whales are basically solitary and they do not display social cohesion which is why they only single strand.

3.2.3.3 Unidentified Large Cetaceans (Fig. 3.8)

There are five events for which species identifications could not be established (even to sub-order level for four events) but which involved large whales (greater than 4.5m) (Nicol 1987).

3.3 Patterns in the Stranding Record

3.3.1 Species Composition

Table 3.2 ranks the 22 species according to the number of stranding events. Nine species with more than five strandings represent 86.% of the events, and five species with more than 20 strandings represent 66.0% of the events.

The pygmy right whale is the most frequent strander around Tasmania, yet it has been recorded on only two occasions. The first sighting was off Bruny Island in 1959 (Guiler 1978). The second was of a pod of whales, tentatively identified as pygmy right whales, 120 nautical miles east south east of Tasmania (Blaber 1986). An inshore movement of this species has been suggested by Davies and Guiler (1957) to explain its high stranding frequency, supported by sightings of animals in shallow water off southern Africa (Ross *et al.* 1975), Victoria (Puddicombe 1988) and Tasmanian coastal waters. Davies and Guiler (1957) proposed that the inshore movement was related to mating and calving activities. In a recent summary of this species, Baker (1985) supported an inshore movement associated with breeding but also noted that pygmy right whales were slow swimmers that hardly showed when at the surface, therefore sightings could be missed or misidentified as minke whales.

The sperm whale is the second most frequently reported strander. The large size of sperm whales would have increased the likelihood of strandings being noticed and recorded. Sperm whales have been sighted off the west and south coasts of Tasmanian (Paterson 1982), a former whaling ground (Crowther 1920; Murray 1927).

The next three species, long-finned pilot whale, common and bottle-nosed dolphins are regularly seen in Tasmanian waters, the two dolphins frequenting nearshore waters (Scott and Lord 1920a, 1920c, 1921; Pearson 1936; Davies 1963; Guiler 1978; Baker 1983; McManus *et al.* 1984).

The false killer whale may be a regular, although infrequent, visitor to Tasmania. The high proportion of herd strandings and the large sizes of their herds will tend to increase the likelihood of their discovery and reporting.

TABLE 3.2

Cetacean strandings around Tasmania to 28 February 1986 ranked according to the number of events per species.

COMMON NAME	SPECIES	NUMBER OF EVENTS
Pygmy right whale	*Caperea marginata*	32
Sperm whale	*Physeter macrocephalus*	31
Long-finned pilot whale	*Globicephala melaena*	30
Common dolphin	*Delphinus delphis*	24
Bottle-nosed dolphin	*Tursiops truncatus*	23
False killer whale	*Pseudorca crassidens*	13
Strap-toothed whale	*Mesoplodon layardi*	11
Cuvier's beaked whale	*Ziphius cavirostris*	10
Gray's beaked whale	*M. grayi*	9
Minke whale	*Balaenoptera acutorostrata*	4
Southern right whale	*Eubalaena australis*	3
Humpback whale	*Megaptera novaeangliae*	3
Killer whale	*Orcinus orca*	2
Blue whale	*Balaenoptera musculus*	1
Sei whale	*B. borealis*	1
Fin whale	*B. physalus*	1
Arnoux's beaked whale	*Berardius arnouxi*	1
Southern bottlenose whale	*Hyperoodon planifrons*	1
Densebeaked whale	*Mesoplodon densirostris*	1
Hector's beaked whale	*M. hectori*	1
Southern right whale dolphin	*Lissodelphis peronii*	1
Short-finned pilot whale	*G. macrorhynchus*	1
Unidentified whales		9
TOTAL		**213**

The next three species that have stranded on more than five occasions are ziphiids, strap-toothed, Cuvier's beaked and Gray's beaked whales. All are oceanic but may be regular visitors to Tasmanian coastal waters. Their unusual appearance would have increased their reporting rates.

Of the thirteen species that have stranded on less than five occasions, southern right and killer whales are both regular visitors to shallow coastal waters around Tasmania (Davies 1963; Guiler 1978; McManus *et al.* 1984). Their familiarity with the shallow water environment is likely to be the main reason for their low stranding frequency (Guiler 1978; Baker 1981a, 1983; McManus *et al.* 1984).

The remaining eleven species appear to be irregular visitors to Tasmanian coastal waters. Some animals may have stranded considerable distances outside their usual distributions. The densebeaked whale may have come from the Indian Ocean (Guiler 1966) while the short-finned pilot whale possibly came from eastern Australia (Scott and Green 1975; Guiler 1978). The baleen whales pass by Tasmania during their annual migrations (Guiler 1978; Baker 1983; McManus *et al.* 1984). The southern right whale dolphin is a sub-antarctic species sighted south of Tasmania on several occasions (Pearson 1936; Guiler 1978; Baker 1981c).

Table 3.3 ranks the species according to the number of animals stranded. The top four species account for 87.4% of all known stranded cetaceans around Tasmania. The long-finned pilot whale, third commonest strander by events, is by far the most numerous strander, with 54.1% of all animals stranded.

The most significant change in ranking occurs with false killer whales, moving from sixth in Table 3.2 to second in Table 3.3. This is due to the high proportion of herd strandings (71.4% of this species' events). A similar pattern was reported from New Zealand (Baker 1981a). The rankings of sperm whales, common and bottle-nosed dolphins have changed due to differences in the proportions of herd strandings (33.3%, 41.7%, and 24% respectively), and numbers of animals per herd stranding (18.8 ± 6.1, 20.4 ± 10.3, 4.5 ± 1.3 respectively). It is interesting to note that bottle-nosed dolphins are lowest in both percentage of herd strandings and number of dolphins per herd stranding. These variations may reflect differences in the size of the usual social units of each species.

TABLE 3.3

Cetacean strandings around Tasmania to 28 February 1986 ranked according to the total number of animals involved per species.

COMMON NAME	SPECIES	NUMBER OF ANIMALS
Long-finned pilot whale	*Globicephala melaena*	1660 +
False killer whale	*Pseudorca crassidens*	548 +
Common dolphin	*Delphinus delphis*	218
Sperm whale	*Physeter macrocephalus*	210 +
Bottle-nosed dolphin	*Tursiops truncatus*	42
Pygmy right whale	*Caperea marginata*	33
Strap-toothed whale	*Mesoplodon layardi*	13
Cuvier's beaked whale	*Ziphius cavirostris*	10
Gray's beaked whale	*M. grayi*	9
Minke whale	*Balaenoptera acutorostrata*	4
Killer whale	*Orcinus orca*	3 +
Southern right whale	*Eubalaena australis*	3
Humpback whale	*Megaptera novaeangliae*	3
Blue whale	*Balaenoptera musculus*	1
Sei whale	*B. borealis*	1
Fin whale	*B. physalus*	1
Arnoux's beaked whale	*Berardius arnouxi*	1
Southern bottlenose whale	*Hyperoodon planifrons*	1
Densebeaked whale	*Mesoplodon densirostris*	1
Hector's beaked whale	*M. hectori*	1
Southern right whale dolphin	*Lissodelphis peronii*	1
Short-finned pilot whale	*G. macrorhynchus*	1
Unidentified whales		251 +
TOTAL		**3016 +**

NOTE: For these species some stranding events have only estimates of the numbers of animals involved, the species are indicated by +

The pygmy right whale, the commonest strander in terms of events, is sixth in terms of the number of animals, due to the species only stranding singly. The rankings of strap-toothed, Cuvier's beaked and Gray's beaked whales remain the same.

In Table 3.3 the ranking of the lower thirteen species, except for killer whales, is the same as that in Table 3.2, as these species are single stranders. One of the strandings of Killer whales occurred in the 1860s and the number of whales involved was not recorded, therefore this species' ranking cannot accurately be determined.

Of the seven strandings for which no species identifications are available (3.3% of the events and 8.2% of the animals) five were herd strandings of unidentified delphinids. The most likely species involved were either of the pilot or false killer whales, due to the size and number of animals involved.

The main features of Tables 3.2 and 3.3 are: the same nine species that account for 86.0% of events also account for 91.1% of the animals; the dominance of long-finned pilot whales (54.2% of animals from 14.2% of events) is due to the high proportion of herd strandings (66.7% of its events); a similar pattern is shown by false killer whales (19.5% animals, 6.6% events, 71.4% herd strandings); the southern right whale and the killer whale are commonly seen but rarely stranded around Tasmania.

3.3.2 General Distribution of Strandings Around Tasmania

The locations of all cetacean strandings are shown in Figure 3.22 and the location of all active strandings in Figure 3.23. Both maps show that four areas have higher rates of strandings than the surrounding coastlines: Circular Head on the north west coast (18.4% of all strandings, 13.8% of single strandings, 29.5% of herd strandings), Storm Bay - lower east coast in the south eastern corner of Tasmania (43.2% of all strandings, 44.7% of single strandings, 39.3% of herd strandings), Macquarie Harbour - Ocean Beach midway along the west coast (5.1% of all strandings, 3.3% of single strandings, 9.8% of herd strandings), and the islands of the Furneaux group on the north eastern corner of Tasmania (6.5% of all strandings, 5.9% of single strandings, 8.5% of herd strandings). There are also two areas with lower stranding rates: the lower west coast - south coast, and the central region of the north coast.

FIGURE 3.22

Distribution of All Cetacean Strandings.

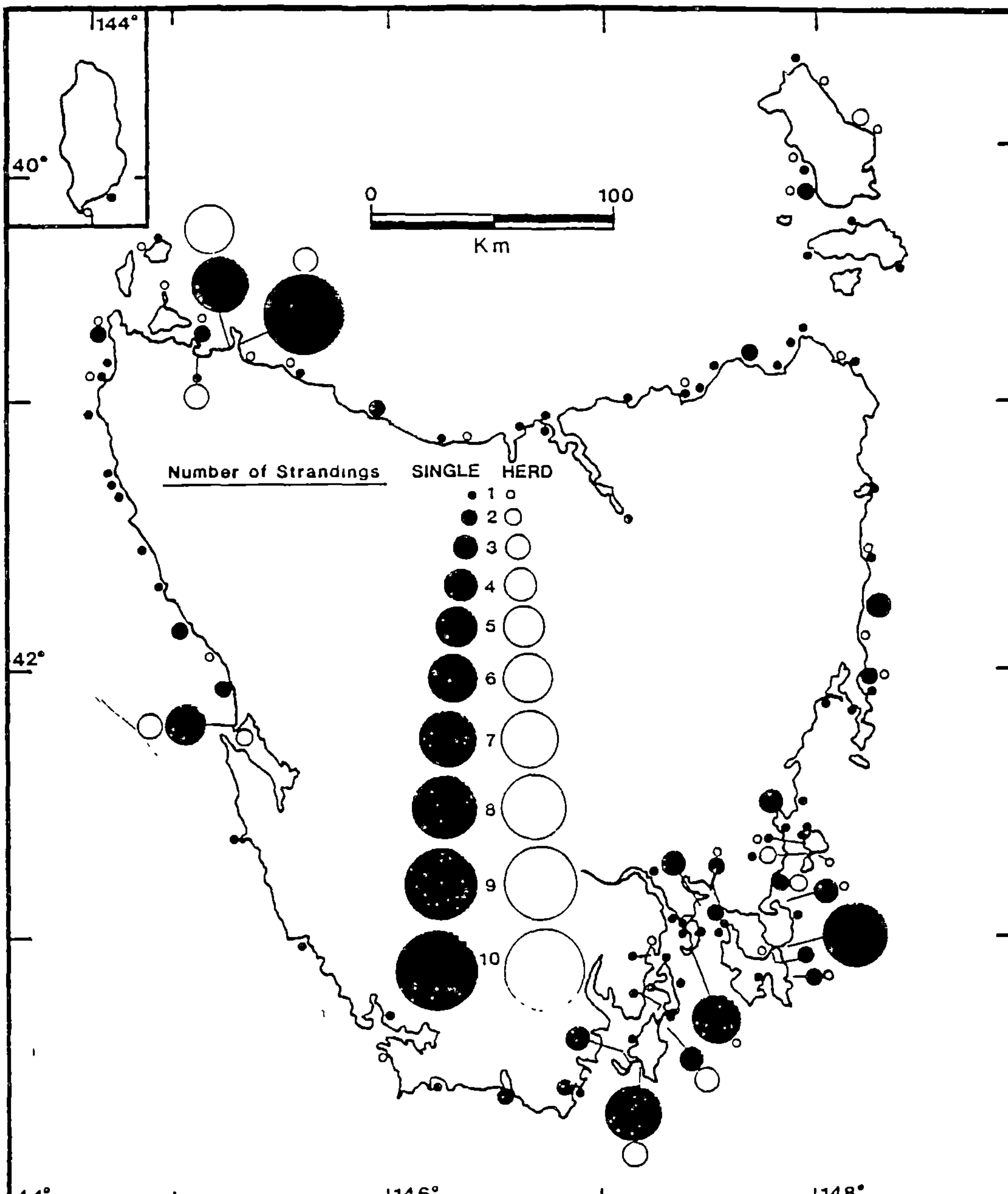
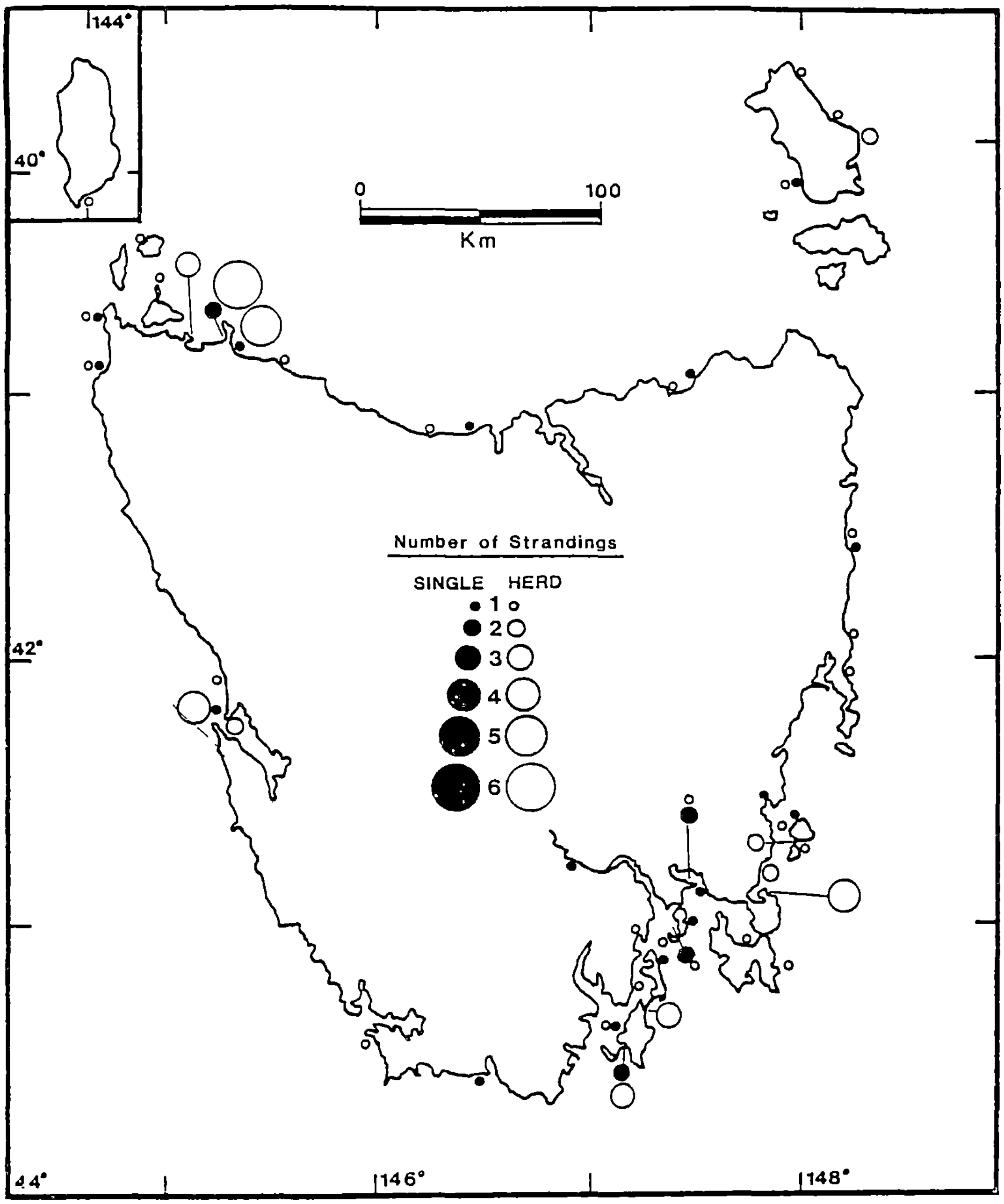


FIGURE 3.23
Distribution of Active Cetacean Strandings.



Factors that influence stranding distributions can be divided into two general groups, those relating to observer effort or those that affect the strandings. Factors affecting observer effort include local population density, access to the coast and the presence of interested people. Factors affecting the strandings include local physical environment, and coastal and geomagnetic topographies, and differences in cetacean activities, such as migration routes, feeding activities and breeding areas.

3.3.3 SEASONALITY OF STRANDINGS (see Sections 3.4.3.2 and 5.2)

The major feature of the frequency of strandings around Tasmania (Fig. 3.24) is the large peak over summer (December to March, $0.001>P(\chi^2 = 43.776)$, df=11). This is predominantly due to single strandings, which themselves show a strong seasonal trend ($0.01>P(\chi^2 = 31.254)>0.001$, df=11). A summer peak, of lesser extent, also occurs in herd strandings ($0.01>P(\chi^2 = 14)>0.001$, df=3).

The summer peak may be due to increased reporting or an inshore movement of some species, possibly related to changes in feeding patterns or distributions of different water bodies, or a combination of both. The summer is also the period of maximum human activity on beaches.

3.3.4 LONGTERM TRENDS IN CETACEAN STRANDINGS (see Sections 3.4.3.2 and 5.3)

The number of reports of cetacean strandings has increased over the years (Fig. 3.25). This increase is made up of both more reports per year and more years with reports. Within this trend are variations in reports between years. The overall increase maybe due to more strandings occurring or a higher proportion of events being reported, or a combination of both. It is not possible to distinguish between these factors. The inter-annual variations are likely to result from differences in stranding rates since fluctuations in reporting rates are likely to operate over the medium term rather than between years.

3.3.5 ZOOGEOGRAPHICAL AFFINITIES OF THE TASMANIAN CETACEAN FAUNA

This section updates the Tasmanian cetacean fauna affinities presented by Guiler (1978). Guiler established three affinity groupings, Cosmopolitan, Austral Circumpolar and Tropical,

Figure 3.24 Number of All Cetacean Strandings reported per Month

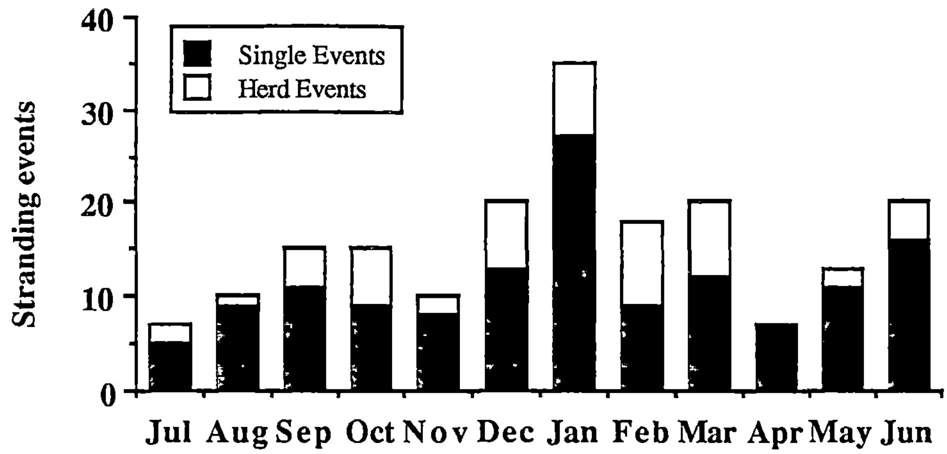
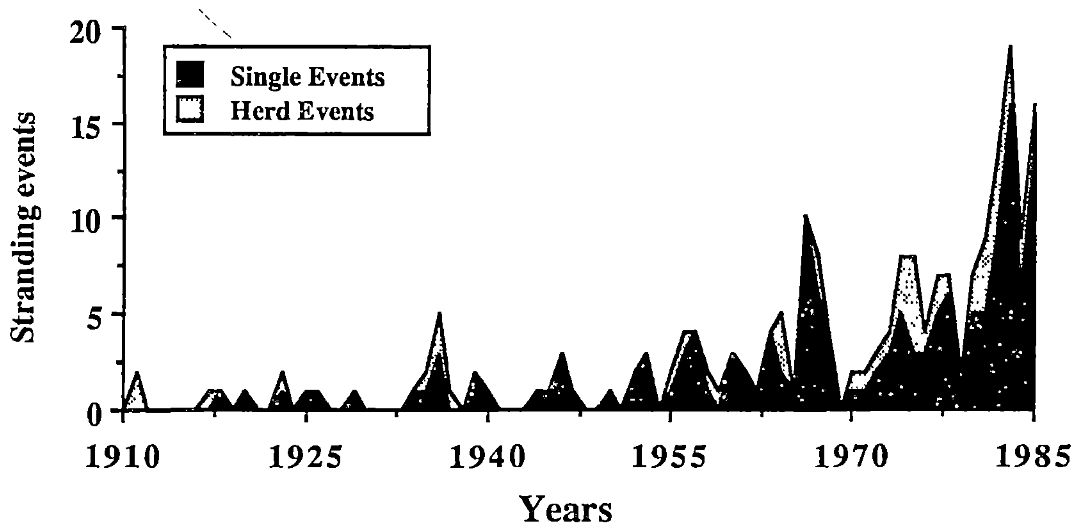


Figure 3.25 Number of All Cetacean Stranding Reports per Year



and listed 20 species then recorded from Tasmania, in addition to 2 species he thought likely to occur around Tasmania. In this work 34 species are listed (Table 3.4). Three species have been added to the stranding record since Guiler (1978) (southern bottlenose whale, sei whale (McManus *et al.* 1984) and the southern right whale dolphin (Baker 1981c)). Nine species, and one genus complex, are included because they may be recorded in the future. Several of the species listed by Guiler have been placed in different affinity categories.

The largest grouping is Cosmopolitan which comprises species that occur in most, if not all, of the world's seas. Austral Circumpolar includes species that occur in most, or all, southern hemisphere seas. Tropical affinity containing species which principally occur in tropical and warm temperate waters. None of the species are restricted to Tasmanian (or Australian) waters. The lack of endemic species is unusual for Tasmanian and Australian mammals but not for cetaceans.

Cosmopolitan: There are 17 species in the Cosmopolitan grouping. Four of these have yet to be reported from Tasmanian waters. The pygmy sperm whale is only represented by a single undocumented mandible (see Section 3.2.2) (see Appendix II). Guiler also considered its close relative, the dwarf sperm whale as a likely to stray into Tasmanian waters. Risso's dolphin (*Grampus griseus*) has been reported from deep coastal waters in many areas of the world but it is rare off southern Australia and New Zealand (Morzer-Bruyns 1971; Baker 1972, 1983; Dawson 1985). Both Davies (1963) and Guiler (1978) suggested that this species may eventually be recorded from Tasmania. The other Cosmopolitan species in Table 3.4 not recorded from Tasmania is True's beaked whale (*Mesoplodon mirus*) which was previously thought to occur primarily in the North and South Atlantic (Gaskin 1982) but two specimens stranded in Australia, significantly increasing its known range (Baker 1983; Warneke 1983).

Austral Circumpolar: Of the 12 species in the Austral Circumpolar grouping three have yet to be confirmed from Tasmanian waters. Tasman beaked whale (*Tasmacetus shepherdi*), is known mainly from strandings around New Zealand (Baker 1981a, 1983), but there have been some strandings around Australia and South America (Mead and Payne 1975; Baker 1983).

Andrew's beaked whale (*Mesoplodon bowdoini*), previously reported from Tasmania but re-identified (see Section 3.2.2), might occur around Tasmania considering that the species has already been reported from the mainland of Australia (Dixon 1970; Baker 1983; Robinson

TABLE 3.4

Zoogeographic Affinities of the Tasmanian Cetacean Fauna. Based on Guiler (1978), Baker (1981a, 1983), Watson (1981), Gaskin (1982), McManus *et al.* (1984) and Dawson (1985).

COSMOPOLITAN	AUSTRAL CIRCUMPOLAR	TROPICAL
Minke whale	Southern right whale	Densebeaked whale
Sei whale	Pygmy right whale	Short-finned pilot whale
Blue whale	Arnoux's beaked whale	+ Bryde's whale
Fin whale	Gray's beaked whale	+ Pygmy killer whale
Humpback whale	Hector's beaked whale	+ Tropical oceanic dolphins
Sperm whales	Strap-toothed whale	
Cuvier's beaked whale	Southern right whale dolphin	
Common dolphin	Dusky dolphin[a]	
Bottle-nosed dolphin	Hourglass dolphin[a]	
Long-finned pilot whale	+ Tasman beaked whale	
Killer whale	+ Andrews' beaked whale	
False killer whale	+ Commerson's dolphin[b]	
Pgymy sperm whale[a]	+ Spectacled porpoise[b]	
+ True's beaked whale[c]		
+ Dwarf sperm whale		
+ Risso's dolphin		

NOTES:

a Reported in Tasmanian from a single undocumented museum specimen.

b Restricted mainly to the waters around some subantarctic islands and the coasts of South America, south of 42°S.

c Reported mainly from North and South Atlantic Ocean, but two strandings have occurred in Australia.

\+ Species that are likely to occur in Tasmanian waters, but for which there are no reports to date.

1984). The dusky and hour-glass dolphins have been previously reported (see Section 3.2.2). The dusky dolphin, primarily a coastal species, has been sighted off the southeast coast of Australia (Baker 1983) and the hour-glass dolphin, an oceanic species mainly from subantarctic and antarctic waters, has been reported south of Tasmania (Morzer-Bruyns 1971; Gaskin 1982; Baker 1983; Leatherwood and Reeves 1983) thus they may be confirmed from Tasmania. The spectacled porpoise (*Australophocoena dioptrica*) was formerly believed to be restricted to southern South America, but it has been reported recently, both from sightings and strandings, from subantarctic islands south of New Zealand (Auckland Island) and Tasmania (Macquarie Island) (Baker 1977, 1983; Leatherwood and Reeves 1983; Fordyce *et al.* 1984; Barines 1985). Thus it is possible that this species may eventually be reported from Tasmania, as has the southern right whale dolphin.

Guiler (1978) suggested two other Austral species, Hector's dolphin (*Cephalorhynchus hectori*) and Commerson's dolphin (*C. commersonii*) as possibly occurring off Tasmania. This is considered unlikely as both species have very restricted distributions (Gaskin 1982; Leatherwood *et al.* 1983).

Tropical: While Cosmopolitan and Austral Circumpolar species are expected in Tasmanian waters, Tropical species, however, are not. Guiler (1978) suggested that tropical species may occasionally stray into Tasmanian waters, and the single strandings of two Tropical species (densebeaked and short- finned pilot whales) support this notion. Guiler (1978) proposed that *Feresa intermèdia* (an old synonym for *Feresa attenuata*, the pygmy killer whale), and spotted and spinner dolphins (*Stenella* spp.) may eventually be recorded in Tasmanian waters. Bryde's whale (*Balaenoptera edeni*) has been reported from strandings on the coasts of Victoria and South Australia (Dixon 1970; Baker 1983; Warneke 1983; Puddicombe 1987), suggesting that it may eventually strand around Tasmania.

3.3.6 CONCLUDING REMARKS

This examination of the Tasmanian cetacean stranding record has identified several features of the species composition, distribution and seasonality worth further investigation.

Species Composition: Twenty two species have stranded around Tasmania. Five species (pygmy right, long-finned pilot and sperm whales, and common and bottle-nosed dolphins) are common members of the fauna, based on strandings and, for some, sightings. Two other species (southern right and killer whales) also are common members of the fauna but based on their sighting record. Four species (false killer, strap-toothed, Cuvier's beaked, and Gray's beaked whales) strand regularly and therefore are regarded as recurrent visitors to Tasmanian waters. The twelve remaining species are either infrequent or rare visitors to Tasmania.

Distribution of Strandings: Four areas have relatively high stranding frequencies, Circular Head, Storm Bay-lower east coast, Macquarie Harbour-Ocean Beach and the Furneaux Group, and two areas have low stranding frequencies, lower west coast-south coast and central north coast.

Seasonality of Strandings: Most strandings, both single and herd, are reported during summer, due to possible increases in cetacean activities near the coast.

Longterm Trends in Strandings: Overall the number of stranding reports has been increasing over the years.

3.4 EFFECTS OF OBSERVER EFFORT ON THE TASMANIAN CETACEAN STRANDING RECORD

3.4.1 INTRODUCTION

Differences in frequencies of stranding reports with time and between locations are important aspects of any stranding record (Mead 1979; Baker 1981a; Klinowska 1985a). The potential causes of these differences can be divided into three categories; cetacean activity, physical environment and human activity. A combination of these factors are likely to be the actual causes. To test the extent to which cetacean activities and/or features of the physical environment effect strandings the influence of human activities need to be known. This section attempts to determine the level of human influence on the Tasmanian record and remove it, as far as possible.

Human activities involved with strandings include the discovery, reporting, examination and recording of events which collectively can be called "observer effort". The influences of these activities start after a stranding has occurred, unlike biological and physical factors, which no longer have any effect at this stage. Discovery and reporting of cetacean strandings is largely dependent on the erratic efforts of the general public. Recording events is dependent firstly on their discovery and subsequent reporting, and secondly on the aims and interests of the individuals or institutions involved. Mead (1979) noted that prior to the systematic recording of strandings rare and/or unusual species were more likely to be reported and recorded than common species.

The question of observer effort increases in importance when examining the stranding record for long-term trends and possible causes (Sheldrick 1979; Barzdo 1985). In general, relationships between the distributions of strandings and observer effort have been found with the United Kingdom (Easton *et al.* 1982; Kayes 1985; Klinowska 1985a), and American stranding records (Mead 1979; Dailey *et al.* 1979). Unfortunately, it has been not possible to quantify observer effort, although, rough indicators may be able to provide qualitative measures of observer effort (International Whaling Commission 1986).

The distribution of observer effort around Australia is very uneven, being concentrated near population centres (Barzdo 1985; International Whaling Commission 1986). For example, Dixon (1980) noted that strap-toothed whale strandings appeared to correlate with centres of cetacean research.

In Tasmania, several authors have commented on differences in the rates of strandings around the coast and through time. Guiler (1978) noted an increase in the numbers of strandings each year which he suggested were due to more strandings *per se* rather than greater reporting resulting from heightened public interest. Guiler did not suggest possible reasons for the increases in the rates of strandings. More recently, McManus *et al.* (1984) suggested that increases in strandings resulted from more frequent reporting, due in part to greater public mobility. Guiler (1978) and McManus *et al.* (1984) both commented on the uneven distribution of strandings around Tasmania, suggesting that features of the physical environment were the cause but they did not comment on the influence of observer effort.

Following the review of the Tasmanian records (section 3.2), it is opportune to assess the influence of observer effort, for example are the high concentrations of strandings in some areas due to the areas' physical features or because they are popular holiday areas. This section has been divided into two sections. The first part develops a qualitative assessment of observer effort. The second part evaluates the effects that geographic, temporal and seasonal variations in observer effort may have had on the Tasmanian stranding record, thereby identifying those sections of the record most suitable for detailed analysis.

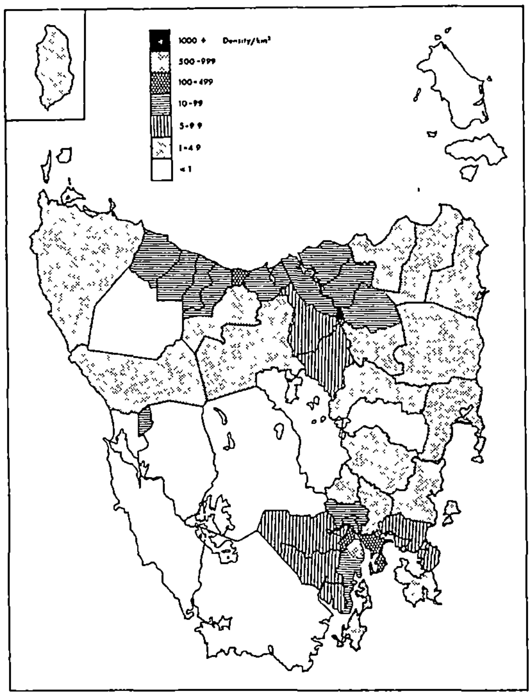
3.4.2 INDICATIONS OF OBSERVER EFFORT

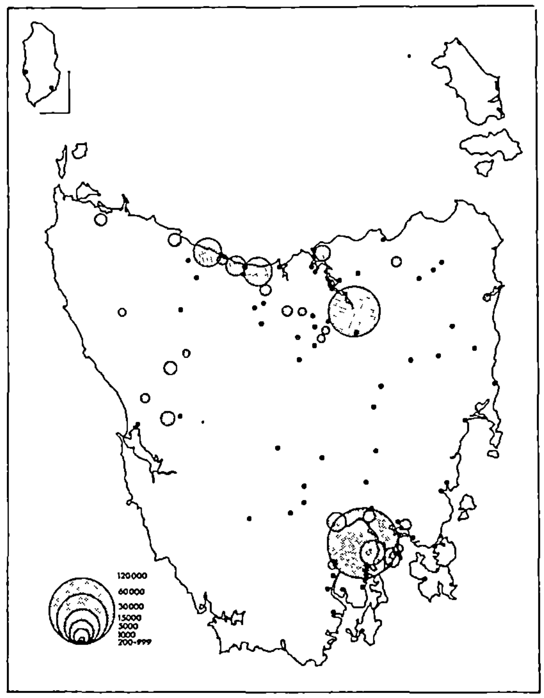
3.4.2.1 INTRODUCTION

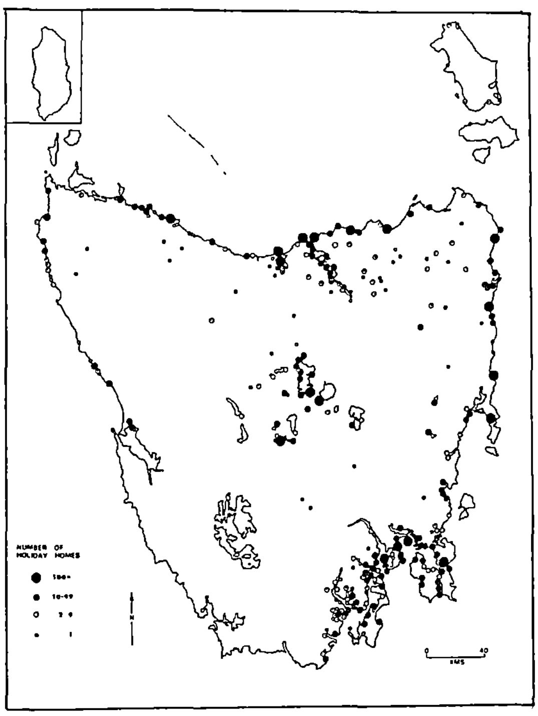
Most stranding reports around Tasmania come from the public, following the opportunistic discovery of events which means that it is not possible to quantify observer effort. Two indirect measures of human activities around the coasts are useful as they indicate potential beach use; namely distributions of human population and coastal holiday dwellings.

3.4.2.2 HUMAN POPULATION DISTRIBUTION

Two slightly different, but related, measures of human population distribution are examined: population density by local government areas, (Fig. 3.26), and location of population centres (Fig. 3.27) (after Cocking 1985). Human distribution has remained basically the same since at least 1966 (Lakin 1971), but has changed markedly since 1847 when the population was







CLOCKWISE FROM THE TOP LEFT

Figure 3.26

Distribution of population density, per Local Government Areas, around Tasmania (from Cocking 1985).

Figure 3.27

Distribution of population centres around Tasmania (from Cocking 1985).

Figure 3.28

Distribution of holiday dwellings around Tasmania, in 1977 (from Thorne 1977) smaller and restricted to the central north coast and south east of the State (Denison 1849). The present population distribution is uneven, the central north coast and the south eastern area (Storm Bay) have relatively high population densities while the southern section of the west coast, the south coast and the islands of the Furneaux Group (north east) have very low densities.

A similar pattern is seen with population centres, with major centres occur along the central section of the north coast and in the south east. Minor centres are spread along most of the north and east coasts. A single coastal centre occurs on the west coast at the entrance to Macquarie Harbour. King Island has two small population centres. The number of holiday makers and level of fishing activity around the islands of the Furneaux Group would increase the level of human activity in this area beyond that indicated by population level.

3.4.2.3 Coastal Holiday Dwellings

The other indirect measure of beach use is the distribution of coastal holiday dwellings (Fig. 3.28) (after Thorne 1977), which most likely has changed since 1976 due to the increase in the population.

Large numbers of holiday dwellings are located around Storm Bay and the D'Entrecasteaux Channel in the south east, and along the central section of the north coast. There are local concentrations scattered along the east coast and, to a lesser extent, along the northern section of the west coast. There are a few holiday dwellings on the islands of the Furneaux Group. The south coast and the southern section of the west coast have no holiday dwellings, though there is a walking track along the south coast which during summer has reasonably heavy bushwalking traffic. (Bushwalkers have provided some of the stranding reports from this area: McManus *et al.* 1984).

3.4.2.4 Qualitative Estimates of Observer Effort

The major features of the Tasmanian population distribution can be summarised as follows:

1. There are high concentrations of people and holiday dwellings on the central section of the north coast and in the south east of the State;
2. There are very low concentrations of people and holiday dwellings on the southern section of the west coast and the south coast; and,

3. The remainder of the coastline has low concentrations of people and holiday dwellings, with a few scattered minor centres.

From this summary it is possible to develop three qualitative categories of observer effort around Tasmania:

good observer effort	areas with high densities of both population and holiday dwellings;
medium observer effort	areas with medium to low densities of population and holiday dwellings; and,
poor observer effort	areas with very low or nil densities of population and holiday dwellings.

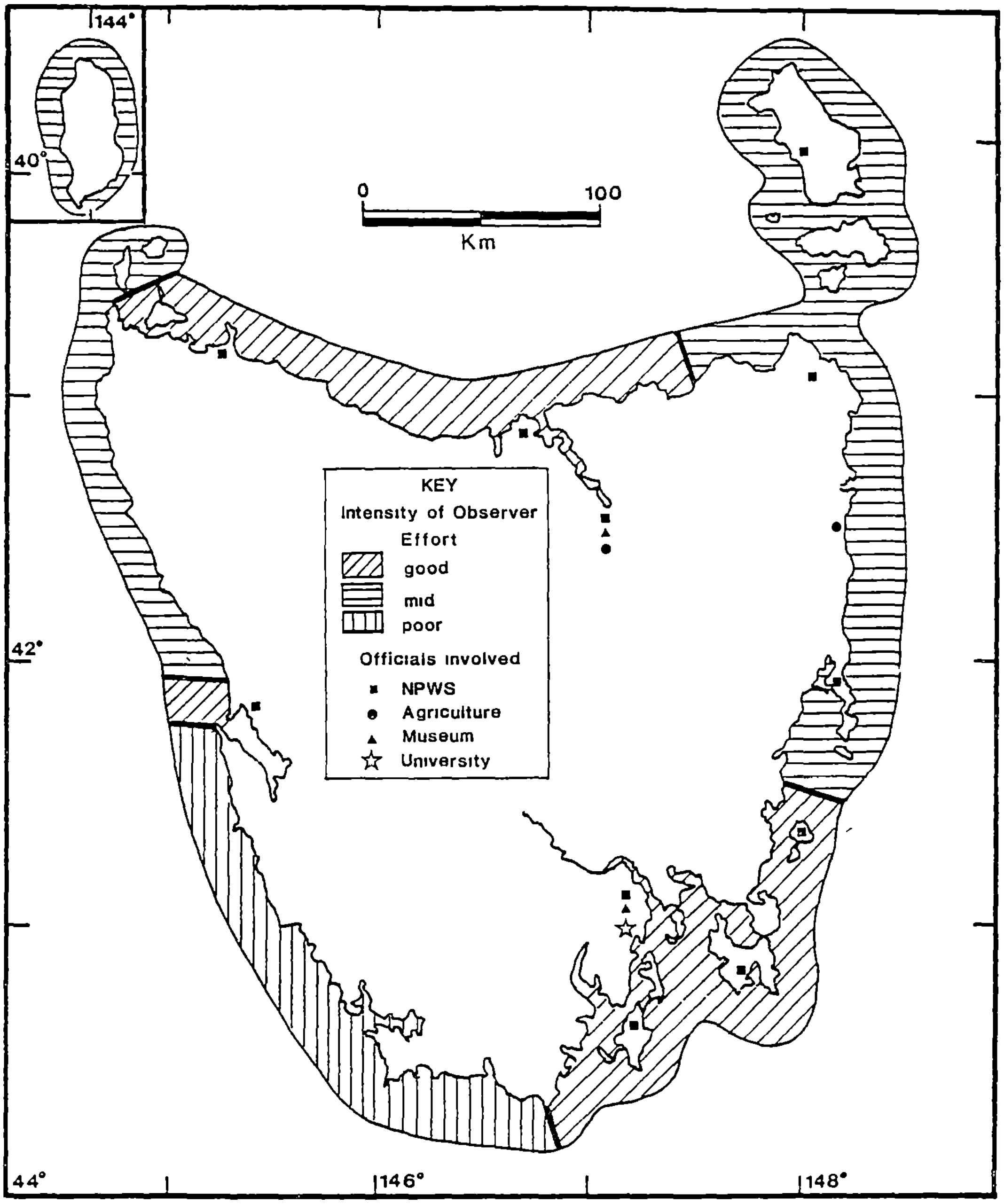
The pattern of observer effort around Tasmania, using these three categories, is shown in Figure 3.29. The localized area of good observer effort on the west coast around the mouth of Macquarie Harbour, and the adjacent section of Ocean Beach, is due to two features of this area. It is adjacent to the fishing port and tourist area of Strahan and there is easy access to Ocean Beach

The distribution and extent of camping around Tasmania is unknown but campers may seasonally affect the level of observer effort in an area. The pattern of observer effort may thus need to be changed at a later date to accommodate the influence of campers. It should also be noted that holiday homes may be located in the same areas as strandings because some features of the physical environment are common requirements for both holiday dwellings and strandings, for example sheltered tidal flats and gently sloping beaches.

Figure 3.29 also shows the present-day location of various officials and researchers involved in reporting and examining stranded cetaceans, including rangers and research officers for the Tasmanian Department of Lands, Parks and Wildlife (L.P.W.), veterinarians from the Tasmanian Department of Agriculture, staff from the Queen Victoria Museum in Launceston and the Tasmanian Museum and Art Gallery in Hobart, and researchers from the University of Tasmania.

FIGURE 3.29

Qualitative indication of the distribution of Observer Effort around Tasmania.



3.4.3 EFFECT OF OBSERVER EFFORT ON THE STRANDING RECORD

3.4.3.1 GEOGRAPHICAL INFLUENCES

The geographical influence of observer effort on stranding records may be indicated by a comparison of the distributions of observer effort (Fig. 3.29) and cetacean stranding reports (Fig. 3.22). It needs to be remembered that the stranding data has accumulated over the past 160 years and that the distribution and level of observer effort have changed over that time.

The distribution of cetacean strandings around Tasmania is uneven, four areas have higher and two areas have lower numbers of strandings than their surrounding coasts (Section 3.3.2). Comparisons between observer effort categories and stranding distributions produce two main patterns:

1. Areas with similar relative numbers of strandings and level of observer effort.
   a. High strandings and high observer effort - northwest coast around Circular Head, Storm Bay and the southern east coast, and around Macquarie Harbour,
   b. Medium strandings and medium observer effort - northern section of the west coast, northern section of the east coast, and eastern section of the north coast,
   c. Low strandings and low observer effort - south coast and southern section of the west coast.
2. Areas with marked differences between the number of strandings and the levels of observer effort.
   a. Low strandings and high observer effort - central section of the north coast,
   b. Medium strandings and low observer effort - the Furneaux Island Group.

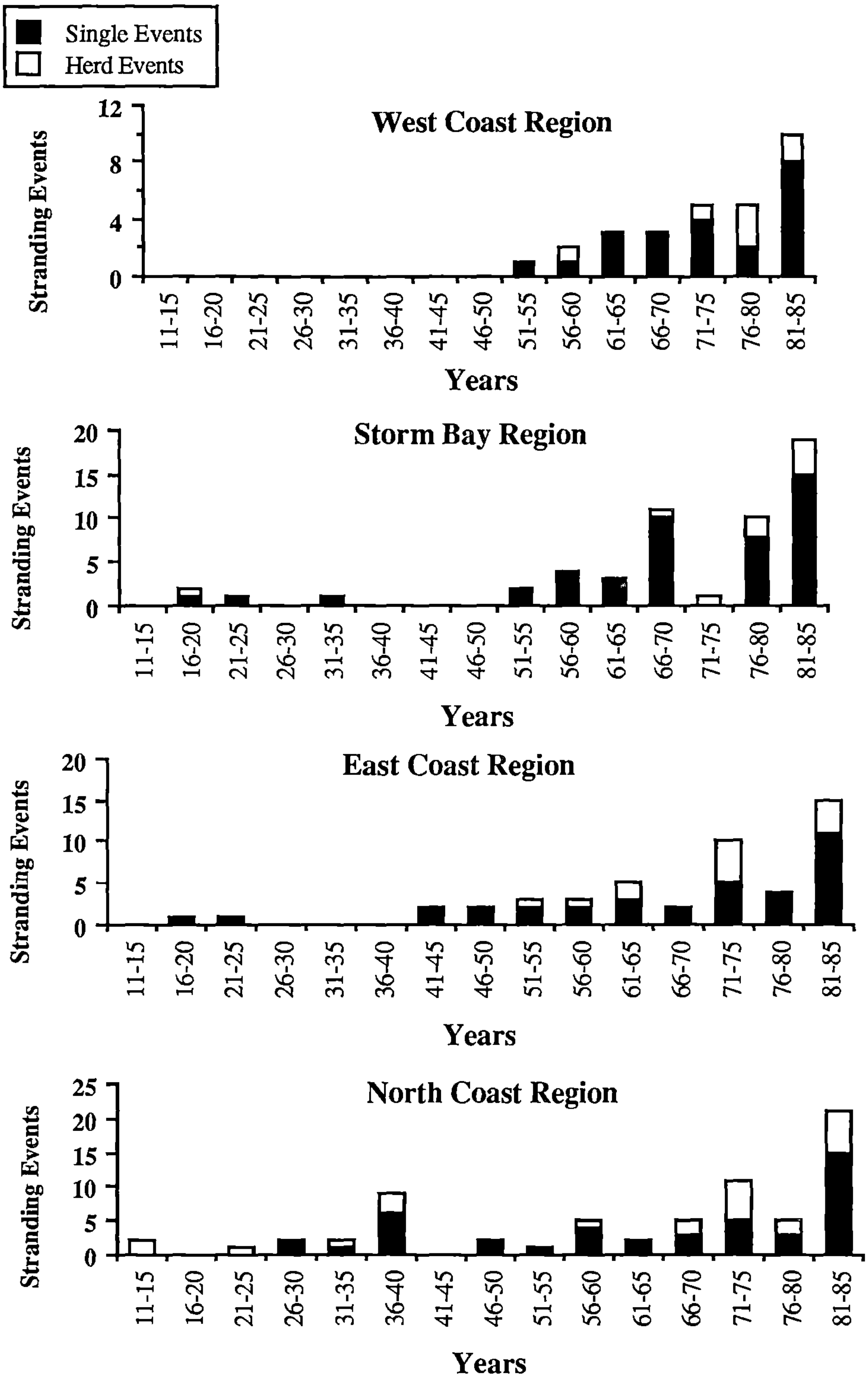
The areas which show either pattern 1a or 2a are the most interesting areas for further analysis.

3.4.3.2 TEMPORAL INFLUENCES

The numbers of strandings reported each year for Tasmania are shown in Figure 3.25 and, in five year groupings, for four coastal regions are shown in Figure 3.30. Both figures show that the number of stranding reports has increased in recent years. The lack of stranding reports in the West Coast Region prior to 1951 is an example of the influence of a low level of observer effort on the record. During the 1920s and 1930s strandings were discovered by huon piners working along the west coast but not reported (Nielson, personal communication 1986). In

FIGURE 3.30

The Number of Cetacean Strandings reported from the four Coastal Regions of Tasmania (in five year groups).



comparison, the large number of strandings recorded from the Northern Coastal Region between 1911 and 1940 resulted from Scott's (1942) attempt to record all strandings of all species.

Since the Tasmanian cetacean stranding record is the accumulation of events over the past 160 years a review of the history of studies, and changes in public interests, in cetaceans around Tasmania may indicate the extent of variations in observer effort with time and possible effects of such variations.

Nicol (1986) reviewed the history of cetology in Tasmania, identifying three changes. The number of active researchers has increased from one amateur naturalist in the nineteenth century, five researchers (mainly museum staff) at various times during the first half of the twentieth century to eight researchers in 1986. The interest and background of the researchers has diversified from those primarily interested in collecting and describing rare and unusual species, to the present where veterinarians and other researchers are interested in many aspects of cetacean biology and ecology. The emphasis has shifted from the collection of rare and unusual specimens to the systematic collection of information as part of a state-wide stranding network, with the primary aim of rescuing stranded animals. These changes in the study of cetaceans in Tasmania have meant that in recent years strandings are more likely to be discovered, reported and, subsequently, recorded.

The interest of the public in cetaceans has increased markedly in recent years. During the 1970s people initially became concerned about the survival of the larger whale species threatened by over-exploitation (Frost 1978). This concern subsequently expanded to encompass stranded animals and their welfare (Bittelman 1982), leading to many rescue attempts, as exemplified by Project Jonah (1981, 1982a, 1982b) and Whiteside (1985, 1987). These rescue attempts increased publicity about cetaceans and their strandings resulting in even greater public awareness of the need and value of reporting all strandings to the authorities (Anderson 1985).

In addition, two major changes have occurred in the general public's behaviours which would increase the level of observer effort. Recreational use of beaches has increased (Thorne 1977) and access to remote beaches has improved through greater availability of four-wheel drive vehicles and trail bikes (McManus *et al.* 1984).

Seasonally, the peak period for the discovery of strandings is December to March (Fig. 3.24), which is possibly due to increases in human activity on and, near, the beaches. It is possible that the same climatic factors that favouring human uses of beaches also create the conditions that bring cetaceans inshore. McManus *et al.* (1984) noted that most events in their study occurred during the summer with two minor peaks that correspond with two school vacation periods (May and August).

Some of the increase in strandings reported during the summer is undoubtedly due to greater observer effort, however, little is known about seasonal movements of cetaceans around Tasmania (apart from the migration of the larger baleen whales), therefore, it is not possible to determine whether seasonal movements exists and, if so, to what extent they contribute to the summer high in stranding reports.

3.4.3 DISCUSSION

It is clear from the above that variations in observer effort have effected the Tasmanian cetacean stranding record. Past and present distributions, and changes over time in observer effort have been significant. There is also seasonal variation in observer effort in Tasmania.

The three areas of Tasmania have relatively high numbers of strandings and high levels of year round observer effort (Circular Head, Storm Bay and Macquarie Harbour), suggesting that they actually have high numbers of strandings. Therefore, caution is needed when comparing these and other areas on the basis of physical or biological features, alone. While strandings reported from the Furneaux Group are not as numerous as the three areas mentioned above, the level of observer effort was lower, thus the actual number of strandings would be expected to be higher than the number of reports.

The two areas with low numbers of strandings (the south coast and southern section of the west coast, and the central section of the north coast) are very different from each other in terms of observer effort. The former has a very low level of observer effort, and it is likely that a low proportion of strandings occurring there are discovered and reported. This area does not appeared suited for detailed examination. The central section of the north coast, on the other hand, has a high level of observer effort indicating that a high proportion of the strandings in this area are recorded, therefore the area has few strandings making it important in any analysis.

The remainder of the Tasmanian coastline has mid to low numbers of strandings and mid to low levels of observer effort. The latter indicates that these areas are under-reported in the stranding record. It is not possible to determine the extent of this under-reporting which reduces the usefulness of these areas for detailed analysis.

The increases in reports of cetacean strandings undoubtedly stems from greater observer effort. The implications are that prior to 1945 most areas of the Tasmanian coast were grossly under-reported. This reduces the usefulness of events prior to 1945. The establishment of the State-wide stranding reporting network and increased public awareness has improved this situation, however, it is likely that some events are still not discovered and/or reported.

The effects of seasonal changes in observer effort on the stranding record are difficult to quantify, since seasonal changes may also occur in the distribution and activities of the cetaceans themselves.

CHAPTER 4 SPATIAL VARIATIONS IN THE TASMANIAN CETACEAN STRANDING RECORD

4.1 INTRODUCTION

The review of the Tasmanian cetacean stranding record conducted in the previous chapter identified that the distribution of cetacean strandings around Tasmania is clumped, oceanic cetaceans constituted a major component of the record and two of the four species regularly seen in Tasmanian coastal waters stranded very rarely. Similar patterns have been reported about stranding records from other areas of the world (Geraci and St Aubin 1979a; Mead 1979; Sheldrick 1979; Baker 1981a; Easton *et al.* 1982; Klinowska 1985a). Hypotheses attempting to explain these features of the record have involved aspects of the physical environment, including of oceanographic conditions and coastal topography (Section 2.3.3.1). Some of these hypotheses where incorporated in the working hypothesis. Predictions of the working hypothesis relating to the distribution of strandings can now be tested against the Tasmanian cetacean stranding record.

This Chapter investigates possible relationships between aspects of Tasmania's oceanography, geographic and geomagnetic topographies, and the distribution of cetacean strandings around Tasmania. Firstly, the role and influence of oceanography on cetacean strandings will be investigated. Unfortunately, it is not possible to relate specific individual strandings to oceanographic features, rather comparisons can be made between the general oceanographic features and overall patterns in the stranding record. Secondly, the geographic topographies of active strandings, both on and offshore, are examined. Two approaches have been used; examining the topographies of stranding sites to see if any topography dominates the record, and comparing the frequencies of various topographies at stranding sites against the frequencies of such locations along the coasts as a whole.

Thirdly, the role that aspects of geomagnetic topography play in determining the location of strandings are examined. Based on the results of earlier studies this examination will concentrate on the intensity and alignment of the geomagnetic contours at active stranding sites. Finally, the combined results from these comparisons will be compared with the predictions of the working hypothesis.

4.2 OCEANOGRAPHIC CONDITIONS

4.2.1 INTRODUCTION

Oceanographic features can influence cetaceans strandings either directly through the animals or indirectly via their prey. The ability of cetaceans to handle coastal oceanographic conditions depends on the combination of their experience and health. Cetaceans entering unfamiliar habitats may not be able to cope with the different oceanographic features encountered. Animals in poor health, for example due to age, parasite infection, injuries, or starvation, are likely to be at greater risk than healthy cetaceans when dealing with unfamiliar conditions.

4.2.2 METHODS

This section presents a comparison between general aspects of the oceanography around Tasmania and the distribution of cetacean strandings. A major limitation was the lack of data concerning micro-scale oceanographic features, the scale of features most likely to affect individual cetaceans. General details about macro-scale features were available but the extent of knowledge about oceanography around Tasmania was very uneven, with the waters off the west and south coasts being largely unstudied (Rochford 1975).

Nicol (1985) compiled a review of the Tasmanian oceanography and the major features identified in that report are summarised below. Nicol divided Tasmania into four coastal regions (see Section 3.2 and Fig. 3.1) on the basis of their characteristic combination of macro-scale occanographic features and general coastal topography. The North Coastal Region (**NCR**) is dominated by Bass Strait and the interaction between wind stress and tidal currents. The West Coastal Region (**WCR**) is exposed to high energy waves and swells generated by westerly winds in the Southern Ocean. The Storm Bay Region (**SBR**) is effected by interactions between its complex coastal topography, two major river systems and the influence of oceanographic features from its two neighbouring regions. The East Coastal Region (**ECR**) is affected by the interaction between warm East Australian Current waters to the north and cool sub-antarctic waters from the south that meet and mix together, forming the Sub-Tropical Convergence Zone (**STCZ**).

Based on their combinations of stranding frequencies and levels of observer effort, four areas of Tasmania have been identified as being worth further investigation (Section 3.4.3). Three of these areas have frequent strandings and high levels of observer effort, being the western end of NCR (around Circular Head), SBR and southern ECR, and Ocean Beach in the WCR. The fourth area, the central section of the NCR, had few strandings but high levels of observer effort. These areas will principally be used in the following comparisons because of the high levels of observer effort indicate that any differences between them are likely to be due to differences in the patterns of cetacean strandings rather than human activities.

4.2.3 RESULTS

SBR AND SOUTHERN ECR.

This area is the most structurally complex section of coast around Tasmania. It includes two large islands (Bruny and Maria), a number of small islands, a large peninsula (Tasman Peninsula), several large shallow enclosed bays, (Ralphs Bay, Big Taylor Bay and Blackmans Water), a few relatively deep bays (Fortescue Bay, Eaglehawk Bay), and extensive areas of tidal flats (Pittwater, Lauderdale and South Arm). The local oceanography of the area will consists of interactions between local tidal and wind driven currents. The major external influences are southwest swells and occasional intrusions of warm oceanic water masses into Storm Bay due to variations in the position of the Sub-Tropical Convergence Zone (Harris *et al.* 1987).

The cetacean species that have stranded most frequently in this area are the common dolphin (Fig 3.4), bottle-nosed dolphin (Fig. 3.6), long-finned pilot whale (Fig. 3.9) and pygmy right whale (Fig. 3.20). The strandings of the two dolphin species mainly occurred on the inner coasts of the region, particularly the tidal flats. These species have been regularly reported from coastal waters around Tasmania (Guiler 1978; McManus *et al.* 1984). Most of the strandings of the long-finned pilot whale were on the outer coasts, particularly the exposed beaches. The long-finned pilot whale is generally considered to be an oceanic species although it occasionally enters coastal waters (Baker 1983; Leatherwood and Reeves 1983). The pattern for pygmy right whale strandings is less defined as there were strandings on both the inner and outer areas of the region. In addition, the health status of the animals involved in most of these events ~~are~~ is unknown.

Several other species have stranded in this region, mainly on the exposed coasts, such as southern Bruny Island. Two notable exceptions are the strandings of a blue whale at New Norfolk and a fin whale in Pittwater (Guiler 1978; Section 3.2.3). Both events involved large oceanic baleen whales travelling considerable distances into the region.

WESTERN END OF THE NCR.

The area is situated at the western end of Bass Strait, within 90 km of deep oceanic water (deeper than 200m) and contains long sandy beaches, large areas of tidal flats associated with shoaling water and several islands immediately offshore, plus the small but prominent peninsula of Circular Head. The interactions between wind stress currents and tidal circulation (heightened by the area's shallow water) are the area's major oceanographic features. In addition, south westerly swells can refract into the area from the WCR.

The species that constitute most of the cetacean strandings in this area are the sperm whale (Fig. 3.2), false killer whale (Fig. 3.11) and pygmy right whale (Fig. 3.20). The first two species are considered to be oceanic, rarely entering coastal waters (Baker 1983; Leatherwood and Reeves 1983). Guiler (1978) and McManus *et al.* (1984) both considered it unlikely that sperm whales pass through Bass Strait because the waters of the Strait are less than 200 metres deep.

CENTRAL SECTION OF THE NCR.

This area is about 200 km from the open ocean and consists of sandy beaches in between rocky headlands with the waters off-shore being generally shallow. The major oceanographic features of this area are the interactions between wind and tidal currents, and the two tidal peaks, one from each end of Bass Strait . Few strandings have been reported from this area. Various delphinid species have stranded in the area, including common dolphins (Fig. 3.4) and long-finned pilot whales (Fig. 3.9). Both the sperm whale (Fig. 3.2) and pygmy right whale (Fig. 3.20) have stranded once in the area.

OCEAN BEACH ON THE WCR.

This is the smallest area under consideration, consisting of a long sandy beach which runs generally north south, sweeping westward at its southern end. There are two important topographical features at the southern end of Ocean Beach, the narrow entrance to Macquarie Harbour and, immediately to the west, the rocky headland of Cape Sorell. The major oceanographic features of this area are frequent high energy south westerly winds and swells, and strong tidal flows through the narrow entrance of Macquarie Harbour.

The cetacean species that account for most of the strandings at this location are the sperm whale (Fig. 3.2) and long-finned pilot whale (Fig. 3.9) with some strandings of the bottle-nosed dolphin (Fig. 3.6) and various beaked whales (Figs 3.13, 3.16 and 3.17).

It is worth recalling the stranding of a densebeaked whale on the northern end of the WCR. The whale may have been transported to Tasmania from the Indian Ocean via the Leeuwin Current (Section 3.2.3.1).

4.2.4 DISCUSSION

The lack of information about specific oceanographic features has prevented a detailed examination of their possible influence on individual cetacean strandings. It has, however, been possible to draw some preliminary conclusions from a comparison of the general oceanographic features around Tasmania with the overall distribution of cetacean strandings.

The complex coastline in the SBR and southern ECR area means that this area has the longest coastline of the areas examined, therefore more strandings would be expected. In addition, the combination of deep oceanic waters near shallow areas and the likely complexity of the micro-scale oceanographic features could lead to the entrapment of cetaceans. Such conditions would be difficult for oceanic species to handle, especially if they had limited experience of inshore conditions. This could have been a contributing factor in the strandings of some of the long-finned pilot and pygmy right whales. The strandings of the two dolphin species appear to be a combination of tidal entrapment in the area's enclosed shallow bays and occasional stranding on open beaches.

The interaction of tidal and wind-stress currents, extensive shoaling areas, islands and a peninsula that occur in the northwest of Tasmania would produce complex oceanographic conditions that could be hazardous for inexperienced cetaceans, particularly oceanic species. McManus *et al.* (1984) suggested that the area's proximity to deep oceanic water meant that oceanic cetaceans occasionally, but apparently mistakenly, enter this area. Then the combination of complex and unfamiliar oceanographic conditions might lead to the stranding of some of these animals. The number of strandings reported from the islands of the Furneaux Group, at the eastern end of Bass Strait, indicates that a similar pattern may be occurring there.

The situation at either end of NCR contrasts with that in the central section. Oceanic cetaceans do not appear to pass through Bass Strait, possibly due to the distance from oceanic waters (Guiler 1978; McManus *et al.* 1984), thus few oceanic cetaceans would get as far as the central section of the NCR. This is generally in agreement with the proposal that oceanic cetaceans only enter Bass Strait by mistake and while attempting to leave some get into difficulties and eventually strand due to the complex and unfamiliar oceanography at either end of the north coast.

Ocean Beach, has been described as a typical whale trap (Rounsevell *et al.* 1981; McManus *et al.* 1984) due to its combination of shelving beach, north-southwest alignment and Cape Sorell jutting out to the northwest blocking off the curve of the beach. These features could lead some cetaceans that were travelling south just off the beach to mistakenly perceive that open water existed to the east of Cape Sorell, thus some may strand on the southern end of Ocean Beach. Alternatively, some of the oceanic cetaceans that enter the area off Ocean Beach may be affected by a combination of the southwesterly swells, local long-shore wind stress currents and tidal flow through the entrance of Macquarie Harbour resulting in some animals get into difficulties and eventually stranding.

4.3 GEOGRAPHIC TOPOGRAPHY

4.3.1 INTRODUCTION

This section examines the topographies of Tasmanian active cetacean stranding sites for any relationships between the frequency of strandings and the types of topographies involved. Also the frequencies of strandings occurring on shelving or steep topographies are compared with the frequencies of these topographies along the whole coast to see if there are any significant differences.

4.3.2 METHODS

4.3.2.1 STRANDING DATA

Only active strandings have been used in this section because aspects of the physical environment were possible influences on the location of these event. Passive strandings, on the other hand, do not involve the physical environment of the stranding site (Kayes 1985; Klinowska 1985a).

4.3.2.2 ONSHORE TOPOGRAPHY

To test whether active strandings tend to occur more frequently on a particular type of coastal topography each stranding site around Tasmania, including the immediate offshore islands, was classified according to its topography into one of three categories[1]: "Enclosed Waters", "Beaches" and "Rocky Shores". The number of events per category was also recorded. The resulting 2x3 contingency table was then tested using the Chi-squared goodness-of-fit test (Snedecor and Cochran 1980). The null hypothesis tested was that the differences between the numbers of events and sites per category were due to chance.

The classification of sites into the categories was based on information from the original description, marine charts and 1:100,000 series topographical maps (Tasmaps; Lands Department, Hobart). Sites in the "Enclosed Waters" category generally have very gentle slopes with very fine substrates (fine sand or mud) which are usually stable. These features are related to the low degree of exposure of the sites to offshore conditions. The category

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1 The pooling of sites may have confounded topographical effects with site effects and results should be interpreted with caution.

"Beaches" involved sites that have gentle slopes, although the actual slopes are variable. The substrate can range from sand to boulders, but they are usually unstable, that is over the short term (hours or days) the substrate under stranded whales can be moved by wave action leading to the burial of the carcasses. The exposure of these sites to prevailing offshore conditions is variable. The final category of "Rocks and Cliffs" includes sites that have steep to very steep slopes, with stable hard substrate. The level of exposure is generally very high. In summary, the major differences between the sites in the different categories are their slopes (very gentle, gentle and steep), substrate (soft, unstable and hard), and exposure (low, mixed and high). The data were not sub-divided into the four coastal regions because the resulting cell frequencies were insufficient to enable meaningful tests to be conducted.

4.3.2.3 OFFSHORE TOPOGRAPHY

To test whether the topography offshore of the sites of active strandings were influencing the location of these strandings active stranding sites from around Tasmania were classified according to the general nature of the topography immediately offshore into one of three categories; "Enclosed Waters", "Shoals and Reefs" and "Open Waters". Again, the numbers of events per category were al,so recorded. The 2x3 contingency table was tested using the Chi-squared goodness-of-fit test (Snedecor and Cochran 1980). The null hypothesis tested was that any differences between the numbers of sites and events in the categories were due to chance.

The sites were classified on the basis of information from the original description and marine charts. The category of "Enclosed Waters" contained sites which are situated within a larger bay, harbour or lagoon which limited access from open waters. Sites in the category of "Shoals and Reefs" had rock reefs (submerged or exposed), islands, shallows or sand banks within one nautical mile of the site, which restricted access from open waters. The category "Open Waters" included sites where there was open water offshore of the site. The general trend between the categories is an increase in the ease of access to the site by cetaceans that were offshore. Again, the data was not sub-divided into the four coastal regions since the small sample sizes were insufficient for statistical testing.

4.3.2.4 COASTAL TOPOGRAPHY

Many researchers have noted that cetacean strandings occur most frequently, if not exclusively, on gently sloping beaches. Researchers have even suggested that some feature, or features, of the beaches caused the strandings. The first step in examining these suggestions was to determine whether the frequencies of strandings occurring on shelving topographies were significantly different from the frequencies of the such topographies along the coast.

A 2.5 km x 2.5 km grid was superimposed on the Tasmanian coastline with each cell containing coastline being classified by the slope of their topography and according to the presence or absence of active strandings. The resulting 2 x 2 contingency tables were tested using Fisher's Exact Test (Zar 1974). The hypothesis being examined was that the frequency of active strandings at sites with shelving topographies were greater than the frequency of such topographies along the coast. The null hypothesis, therefore, was that the proportions of active strandings at sites with shelving topographies were equal or less than the proportions of such topographies.

The coastline examined in this section was restricted to the Tasmania mainland, and Maria and Bruny Islands. The Bass Strait Islands were excluded because suitable maps were not available. Again, the four coastal regions (Fig. 3.1; Nicol 1985) have been used to examine regional differences. Three of these regions were sub-divided. The West and East Coastal Regions were subdivided at latitude 42° 30' S while the North Coastal Region was divided at longitude 146° 30' E (Fig. 3.1).

4.3.3 RESULTS

4.3.3.1 ONSHORE TOPOGRAPHY

A summary of the frequencies of the three topographic features at active stranding sites is given in Table 4.1. The most frequent category was "Beaches" with respect to both the number of sites and events. The "Enclosed Waters" category where the next most frequent. Difference in the frequencies of events and sites in the three categories provided to be very significant, providing strong evidence that the null hypothesis should be rejected, therefore, active strandings occur more frequently at sites in either the "Beaches" or "Enclosed Waters" categories.

4.3.3.2 OFFSHORE TOPOGRAPHY

The pattern of major topographic features immediately offshore of active stranding sites is more complicated with no particular category predominating (Table 4.2). The most frequent categories are "Open Waters" and "Shoals and Reefs". There is very little change in the relative

TABLE 4.1

Active cetacean strandings around Tasmania are examined to see whether they occur independent of the topographies of their stranding sites. Numbers of events are compared with the numbers of sites and tested for goodness-of-fit using Chi-squred Test.

TOPOGRAPHIES	# OF STRANDINGS		STATISTICAL TEST	
	Sites	Events		
ENCLOSED WATERS	14	26	$0.01 > P(\chi^2 = 13.05) > 0.001$	
BEACHES	25	33	reject H_0, **	df = 2
ROCKS AND CLIFFS	5	6		

NOTES:
LEVEL OF STATISTICAL SIGNIFICANCE:
** = Probability of between 0.01 and 0.001 of a good fit, therefore reject H_0

TABLE 4.2

Active cetacean strandings around Tasmania are examined to see whether they occur independent of the topography immediately offshore of their stranding sites. Numbers of sites are compaired with the numbers of stranding events and tested for goodness-of-fit using Chi-squred Test.

TOPOGRAPHIES	# OF STRANDINGS		STATISTICAL TESTS	
TYPES	Sites	Events		
ENCLOSED WATERS	7	10	$0.001 > P(\chi^2 = 20.04)$	
SHOALS & REEFS	13	25	reject H_0, ***	df = 2
OPEN WATERS	22	35		

NOTES:
LEVEL OF STATISTICAL SIGNIFICANCE:
*** = Probability of less than 0.001 of a good fit, therefore reject H_0.

importance of the various topographies when considering the number of stranding events. Again, the differences between the two sets of frequencies were highly significant, providing very strong evidence that the null hypothesis, should be rejected. Cetaceans appear to strand more frequently at sites where the topography immediately offshore could be classified as either "Open Waters" or "Shoals and Reefs".

4.3.3.3 COASTAL TOPOGRAPHY

The comparisons between the frequencies of stranding sites with gentle or steep slopes against the frequencies of such topographies along the coast and the regions are given in Table 4.3. The comparisons for the sub-regions are presented in Table 4.4. The results of the Fisher's Exact Tests for Tasmania and three of the four coastal regions were significant, leading to the rejection of the null hypothesis. The four significant comparisons have similar patterns with active strandings being rarely recorded from rocky coasts while on shelving coasts there were more strandings than expected. These patterns could have resulted from either shelving coasts facilitating strandings or conversely, rocky coasts preventing strandings.

The non-significant Fisher's Exact Test result for the NCR indicates that the frequency of active strandings on shelving sites was not different to the occurrence of these topographies in this region. The only sub-region to have a significant result was the southern section of the ECR, that being a very strong result. The small number of stranding sites in some of the sub-regions meant that cell frequencies were too small to allow for testing.

4.3.4 DISCUSSION

The observation that most active strandings occurred on shelving beaches around Tasmania has been supported by the significant results in the comparison between topographies at active stranding sites. The significant result in the comparison of the categories of topographies immediately offshore of active stranding sites indicates that ease of access to sites may be a factor in determining the location of strandings. Active strandings on the NCR appear to occur independent of the slope of the stranding site. This may have been due to the high proportion of shelving topographies along that section of Tasmania's coasts (Dartnell 1974).

Similar patterns concerning the slope of stranding sites have been reported from other regions of the world, although not necessarily statistically tested (Dudok van Heel 1962, 1966; Robson

TABLE 4.3

Comparisons of the slope of the coastal topography at active stranding sites and the coast, in general, using Fisher's Exact test. The null hypothesis (Ho) is that active strandings tend to occur independent of the slope of the coastal topogarphy.

REGIONS	OBSERVED VALUES			PROBABILITY FROM
	Stranding	No Stranding	Total	FISHER'S EXACT TEST
TASMANIA				
Shelving	34	105	139	
Steep	4	140	144	$P = 2.7 \times 10^{-8}$
totals	38	245	283	reject Ho, ***
NORTH COAST				
Shelving	9	30	39	
Steep	1	18	19	P = 0.089
total	10	48	58	accept Ho
WEST COAST				
Shelving	5	17	22	
Steep	2	53	55	P = 0.018
totals	7	70	77	reject Ho, *
EAST COAST				
Shelving	9	26	35	
Steep	0	34	34	P = 0.0012
totals	9	60	69	reject Ho, **
STORM BAY				
Shelving	11	32	43	
Steep	1	35	36	P = 0.0043
totals	12	67	79	reject Ho, **

NOTES:
LEVEL OF STATISTICAL SIGNIFICANCE:
* = Probability of between 0.05 and 0.01 of a good fit, therefore reject H_0
** = Probability of between 0.01 and 0.001 of a good fit, therefore reject H_0
*** = Probability of less than 0.001 of a good fit, therefore reject H_0.
DEGREES OF FREEDOM: 1

TABLE 4.4

Comparisons of the slope of the coastal topography at active stranding sites and the coast, by subregions, using Fisher's Exact test. The null hypothesis (Ho) is that active strandings tend to occur independent of the slope of the coastal topography.

SUB-REGIONS	OBSERVED VALUES			PROBABILITY FROM FISHER'S EXACT TEST
	Stranding	No Stranding	Total	
Western Subregion of the **North Coast**				
Shelving	7	14	21	
Steep	1	7	8	P = 0.217
totals	8	21	29	accept Ho
Eastern Subregion of the **North Coast**				
Shelving	2	16	18	
Steep	0	11	11	P = 0.3768
totals	2	27	29	accept Ho
Northern Subregion of the **West Coast**				
Shelving	4	12	16	
Steep	2	20	22	P = 0.1523
totals	6	32	38	accept Ho
Southern Subregion of the **West Coast**				
Shelving	1	5	6	
Steep	0	33	33	P = 0.1538
totals	1	38	39	accept Ho
Northern Subregion of the **East Coast**				
shelving	2	22	24	
steep	0	18	18	P = 0.32
totals	2	40	42	accept Ho
Southern Subregion of the **East Coast**				
Shelving	7	4	11	
Steep	0	16	16	P = 0.0003
totals	7	20	27	reject Ho, ***

NOTES:

LEVEL OF STATISTICAL SIGNIFICANCE:

*** = Probability of less than 0.001 of a good fit, therefore reject H_0.

DEGREES OF FREEDOM: 1

1976, 1984; Geraci 1978; Geraci and St Aubin 1979a; Cordes 1981, 1982; Klinowska 1986a). Three categories of explanations have been proposed (see Section 2.3.3.1); the physical structure of shelving coasts caused the strandings, animals tend to remain ashore longer on shelving coasts and observer effort is higher on shelving coasts than on steep rocky coasts. Two or more of these explanations may be acting in combination. Dudok van Heel's echo-location error hypothesis, along with the "whale trap" version, are the most frequently mentioned explanations for how sloping beaches cause strandings. The difficulties with these hypotheses have been discussed in Section 2.3.3.1.

The present results indicate that active strandings tend to occur more frequently on shelving sites with reasonable access to open waters, although not *exclusively*; in this study about 10% of active events occurred on steep coasts, while Klinowska (1986a) reported that 36% of the active strandings reported from around the UK were on steep coasts.

It is not yet possible to determine whether shelving sites are facilitating active strandings or steep sites preventing them. The non-significant results from the NCR provide some degree of support for the latter proposal. There is, also, the possibility that both these explanations combined to produce the distribution of strandings around Tasmania.

4.4 GEOMAGNETIC TOPOGRAPHY

4.4.1 INTRODUCTION

Several authors have proposed that cetaceans, both coastal and oceanic species, navigate by following the local contours of total field intensity and that errors made while using geomagnetic information in their orientation are possible causes, or influences, of strandings (Klinowska 1985b, 1986a; Cornwell-Huston 1986; Kirschvink *et al.* 1986; Walker *et al.* 1986a). Two components of geomagnetic topography that have been identified are total field intensities and alignment of contours of intensity (Klinowska 1985b, 1986a; Kirschvink *et al.* 1986). This section examines the Tasmanian stranding record to see if these two geomagnetic features have had any influence, to check for similar correlations to those already found in earlier studies. Firstly, the Tasmanian geomagnetic field will be examined.

4.4.2 GEOMAGNETIC TOPOGRAPHY OF TASMANIA

Beattie (1978) reviews the available information on Tasmania's geomagnetic field and its origins. He notes that rocks of various ages are associated with geomagnetic anomalies onshore, including Precambrian metamorphic rocks, Jurassic dolerite and Tertiary basalt. Little is known of the chemistry and mineral composition of the continental shelf off Tasmanian, however, it is possible to extrapolate from geological formations that occur onshore and possibly continue offshore.

The structure and shape of the Tasmanian magnetic field vary around the state. Off northwestern Tasmania and in Bass Strait there are several linear anomalies that run between NW-SE and NNW-SSE, some of which appear to be extensions of geological formations found in Tasmania and/or Victoria. Off the west coast, south of Macquarie Harbour, numerous offshore anomalies occur with general S-N to NNW trends, with little continuity with geological formations on-shore.

Off the east and southeast of Tasmania there are no well-defined linear anomalies in the continental shelf area. There are some large deep anomalies at some distance off the coast, possibly off the continental shelf. Beattie (1978) suggests that Jurassic dolerite formations are the most likely source of such large anomalies in the southeast of the state since the rocks with high anomalies from Tasman Peninsula to the southwest of Bruny Island are predominantly dolerites. Beattie suggested that the "confused trends" off-shore may also be the result of doleritic formations beneath the seabed but was unable to support this suggestion.

4.4.3 METHODS

The geomagnetic data were obtained from four maps displaying the results of aeromagnetic surveys conducted off the west, south and east coasts of Tasmania in 1966 by ESSO (Beattie 1978). The maps were made available by the Tasmanian Department of Mines. Unfortunately, not all of the continental shelf around Tasmania was covered, with the north coast, the Bass Strait Islands and inner areas of Storm Bay not being included. In the following analysis when all available areas are being considered together they will be referred to as "Tasmania". Three of the four coastal regions (see section 3.2.1.1) occur within the study area and form useful divisions of Tasmania for the following analysis. The West and East Coastal Regions are divided into sub-regions along latitude 42° 30'S.

Active strandings have been used exclusively because the physical environment surrounding the stranding site may have been involved, in some way, in determining the location of the stranding. Twenty three active stranding sites were located within the study area, representing 39 stranding events.

A grid, with lines running N-S and E-W, was used to overlay the four aeromagnetic maps to provide coastal locations with which to calculate the mean total field intensity for each coastal region and sub-region. The grid also provides the cells for the Fisher's Exact test of the alignment of the geomagnetic contours (Section 4.4.3.2) where each cell containing coastline was scored for the presence or absence of active strandings and for either perpendicular or parallel geomagnetic intensity contours.

A 5 km x 5 km grid was initially chosen as this was the size used in the UK study (Klinowska 1985b, 1986a), however, the cells proved too large to accurately score due to the variation in the alignment of their contours. To minimise this variation the grid was reduced to 2.5 km x 2.5 km, increasing the number of cells containing some coast by a factor of two and increasing the number of cells which contained strandings because of the separation of neighbouring events into different cells.

4.4.3.1 INTENSITY

Two independent methods were used to investigate whether active stranding sites tended to occur at, or near, minima in geomagnetic intensity. The first method compared the mean intensity of stranding sites with the mean intensity for the coastal region or sub-region. The second method compared each site's intensity with the minimum and maximum intensity for the coast over a series of distances either side of the stranding site.

COMPARISON OF MEANS

Comparisons between the mean geomagnetic intensities of active strandings and the coasts were performed with Student's t test (Snedecor and Cochran 1980). The null hypothesis being examined was that any differences between the mean intensities were due to chance, therefore the two data sets came from the same overall population. The alternative hypothesis was that active strandings tend to occur at, or near, either minima or maxima in the total field intensities.

The relative magnitude of the two means determined whether strandings tended to occur near minima or maxima. The comparisons between regions were tested using a one-way ANOVA while the within region differences were tested with a two-way ANOVA (Sokal and Rohlf 1969). The null hypothesis being tested was that the within group variations were greater than the between groups variations therefore the samples are from the same population The alternative hypothesis was that a trend of increasing intensity from north to south may exist within the Tasmanian geomagnetic field.

NEIGHBOURHOOD ANALYSIS

The second method, called "neighbourhood analysis", compared the geomagnetic intensity of each stranding site with the maximum and minimum intensities of the surrounding coastline and then grouped the comparisons for testing. This method is based on the notion that if active cetacean strandings are occurring at, or near, local geomagnetic minima (or maxima) then the geomagnetic field on either side of the stranding site should increase (or decease) away from the site. Kirschvink *et al.* (1986) used this approach with active cetacean strandings along the eastern seaboard of the US and their method has been followed here.

Kirschvink *et al.* (1986) used the following equation to compare the geomagnetic intensity of each stranding site with an estimate of the mean intensity of the surrounding coast

$$x_{i,r} = \left(\frac{B_{i,max} + B_{i,min}}{2} \right) - B_{ith\ stranding} \qquad - ①$$

where "$B_{i,max}$" and "$B_{i,min}$" are the maximum and minimum geomagnetic intensities, respectively, within a radius of "r" km from the ith stranding, and "$B_{ith\ stranding}$" is the geomagnetic intensity of the ith stranding. The initial radius used in the present study was 2.5 km, then increased by 2.5 km intervals to a maximum of 10 km, where possible. The radius was not increased for samples where the coastline was interrupted by major harbours, river mouths or substantial changes in the alignment of the coast.

The resulting values, the average "magnetic field deviation parameters" ($x_{i,r}$), were tested to see if they were significantly different from chance, that is equal to zero. Positive values imply that active strandings occur near local geomagnetic minima while negative values imply that they occur near geomagnetic maxima. Student's t test was considered a suitable measure of deviation from zero, using the following equation

$$t = \frac{\bar{x}_r \sqrt{n}}{s} \qquad - ②$$

where "$\bar{x}_r$" is the mean of the values derived from equation ① at distance "r", n is the number of events, "s" is the standard deviation and "t" is the Student's t value, with (n -1) degrees of freedom. Large values of "t" lead to the rejection of the null hypothesis (that the geomagnetic intensities of active stranding sites are not related to either local maxima or minima but randomly distributed about the mean). The alternative hypothesis was that active cetacean strandings are located at, or near, local geomagnetic minima or maxima, depending on whether the sign of the Student's t value is positive or negative, respectively.

Differences in the data available for this study and that in Kirschvink *et al.* (1986) resulted in modifications to the method. Kirschvink *et al.* had coastline and geomagnetic data on computer which enabled them to conduct multiple runs involving random locations as controls for the active stranding sites. It has not been possible to conduct similar controls in this study.

Another change was the use of 2.5 km steps, to a maximum of 10 km, in the present study rather than the 5 km steps, up to and including 100 km, used in Kirschvink *et al.*. This is due to the size and shape of Tasmania and limitations in the geomagnetic data. Major changes in the alignment of the coastline meant it was not always possible to obtain 10 km of coastline on both sides of a stranding for all events, let alone the much larger radii used in Kirschvink *et al.* (1986).

4.4.3.2 CONTOURS

The cells obtained from the 2.5 km x 2.5 km grid system were used to test whether active strandings tended to occur in areas where the contours of geomagnetic intensity crossed the coast or strandings were randomly distributed with respect to geomagnetic contours. The cells where classified according to the alignment of their contours and for the presents or absence of active strandings, producing 2 x 2 contingency tables that were tested using Fisher's Exact Test (Zar 1974). The null hypothesis being tested was that active strandings occurred randomly with respect to the alignment of the geomagnetic contours to the coast.

4.4.4 RESULTS

4.4.4.1 INTENSITY

COMPARISON OF MEAN INTENSITIES

The means of the geomagnetic intensities for active stranding sites and random locations around Tasmania[2], the three coastal regions and Southeastern Tasmania are displayed in Table 4.5. The comparison for Southeastern Tasmania showed a significant difference, leading to the rejection of the null hypothesis and indicating that strandings tended to be near or at the intensity minima of the area. When conducting multiple Student's t tests on the same data there is an increased probability of producing a type I statistical error, which can be protected aganist by increasing the minimum level of rejection to 0.01 (Zar 1974). The significant result for Southeastern Tasmania is greater than 0.01, therefore it can not be distinguished from chance.

A general trend in the geomagnetic field does appear to exist around Tasmania as shown by comparisons between, and within, coastal regions (Table 4.6). The results of the ANOVAs indicate that the differences between and within the regions were too large to have been due to chance. Overall, geomagnetic intensities in the southeast of Tasmania are higher than along the

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2 None of the random locations were also stranding sites.

TABLE 4.5

Comparisons between geomagnetic field intensities in nanoTesla (nT) from random locations (coastline) and active stranding sites (stranding) around Tasmania, and for three coastal regions, tested using Student's t test.

REGIONS	DATA SET	N	MEAN ± SE	RANGE (NT)	COMPARISON
	coastline	106	6659 ± 10.1	6639-6679	df=127
TASMANIA					P(T=1.28)=0.20
	stranding	23	6630 ± 13	6605-6656	NS
	coastline	42	6629 ± 16.5	6597-6661	df=46
WEST COAST					P(T=0.29)>0.20
	stranding	6	6616 ± 31.2	6555-6677	NS
	coastline	17	6741 ± 28	6686-6796	df=19
STORM BAY					P(T=0.96)>0.20
	stranding	4	6683 ± 40	6605-6761	NS
	coastline	47	6655 ± 11.9	6632-6678	df=58
EAST COAST					0.2>P(T=1.48)>0.10
	stranding	13	6620 ± 12.5	6595-6644	NS
	coastline	35	6724 ± 15.5	6694-6754	df=45
SE TASMANIA[1]					0.02>P(T=2.47)>0.01
	stranding	12	6655 ± 14.6	6626-6684	*

NOTES:

1 **SE Tasmania** is a combination of the data from Storm Bay and the southern sub-region of the East Coast

Level of statistical significance

* Probability of between 0.05 and 0.01 of being from the same sample, therefore reject H_0

SE Standard Error of the mean

df degrees of freedom, $(n_1 - 1) + (n_2 - 1)$, where n_1 and n_2 are the number of items in each of the compared samples.

TABLE 4.6

Comparison between the geomagnetic field intensity in nanoTesla for random locations from within three coastal regions and four sub-regions of Tasmania, using an One-Way ANOVA for the regions and a Two-Way ANOVA for the sub-regions.

BETWEEN REGIONS COMPARISON

Regions	Mean ± SE	n
West Coast	6629 ± 16.5	42
Storm Bay	6741 ± 28	17
East Coast	6655 ± 11.9	47

One-Way ANOVA Table

Source	df	SS	MS	F	Significance
Among Group (coasts)	2	152 516	76258	7.958	**
Within Groups (sites)	103	986 975	9582.28		
Total	105	1139 491			

BETWEEN SUB-REGIONS COMPARISON

Regions		Mean ± SE	n
East Coast	Northern	6622 ± 14.2	29
	Southern	6707 ± 14.3	18
West Coast	Northern	6608 ± 29.3	21
	Southern	6650 ± 14.4	21

Two-Way ANOVA Table

Source	df	SS	MS	F	Significance
A (sub-regions)	1	79728	79728	10.0449	**
B (coasts)	1	15032	15032	1.8939	NS
AxB (interaction)	1	19412	19412	2.4457	NS
Within (error)	85	674 659	7937.2		
Total	88	788 831			

NOTES:

Level of Statistical Significance
** = Probability of between 0.01 and 0.001 of a good fit, therefore reject H_0
NS Not Statisticaly Significant
SE Standard Error of the mean: SS Sums of Squares; MS Mean Sums of Squares
df degrees of freedom, $(n_1 - 1) + (n_2 - 1)$

WCR and northern ECR. This is in general agreement with the summary of the Tasmanian geomagnetic field (Beattie 1978).

NEIGHBOURHOOD ANALYSIS

Neighbourhood analysis has been used to examine whether individual stranding events occur near local minima or maxima. Twenty nine active stranding events, involving nine cetacean species, were examined at radii of 2.5 km and 5 km. The number of available events decreased with greater radii, with 26 events at 7.5 km and 19 events at 10 km. The number of events for each species ranged from 10 for long-finned pilot whales to 3 or 4 events for most species to one event for southern right and densebeaked whales.

The results of the neighbourhood analysis are shown in Table 4.7, which gives the mean (and standard error) of the magnetic field deviation parameter derived from equation ① (in nanotesla, nT), the Student's t value from equation ② with its levels of significance plus the degrees of freedom, for each species and species group at the four radii. The means of each of these species and species groups are depicted in Figures 4.1 (A-N).

Active cetacean strandings tended to occur at, or near, local geomagnetic minima as indicated by the significant values for All Active Strandings (Table 4.7A and Fig. 4.1A) at all radii. When the data sets are reduced to individual species only Long-finned Pilot Whale (Table 4.7J and Fig. 4.1J) has significant values at all radii. Bottle-nosed Dolphin (Table 4.7N and Fig. 4.1N) are significant only at the 5 km radius. These results indicate that Long-finned Pilot Whale and Bottle-nosed Dolphin tend to strand at, or near, geomagnetic minima.

The very small sample sizes of the other species were a major factor in the lack of significant results. This suggestion is supported by the significant values obtained when related species are grouped together, such as Oceanic Cetaceans (Table 4.7B and Fig. 4.1B), Oceanic Toothed Whales (Table 4.7E and Fig. 4.1E), Beaked Whales (Table 4.7G and Fig. 4.1G), Oceanic Delphinidae (Table 4.7I and Fig. 4.1I) and Combined Dolphins (Table 4.7L and Fig. 4.1L). The negative mean geomagnetic field deviation parameters for Beaked Whales, at 10 km (Table 4.7G and Fig. 4.1G) and for All Baleen Whales, at 2.5 km radius (Table 4.7C and Fig. 4.1C), seem to indicate that these whales strand near local geomagnetic maxima.

TABLE 4.7

Comparisons of geomagnetic intensities (in nT) from the sites of active cetacean stranding with the minimum and maximum intensities from the coast at various radii (in kilometers) around each stranding site. The comparisons where conducting using Neighbourhood Analysis and tested for deviation from zero with Student's t test.

DATA SET	RADIUS	N	MEAN ±	SE (NT)	STUDENT'S T VALUE	RESULT	DF
A ALL ACTIVE STRANDINGS	2.5	29	59.05	19.81	0.01>P(T=2.98)>0.005	**	28
	5	29	66.47	19.66	0.005>P(T=3.38)>0.001	**	28
	7.5	26	98.08	21.86	P(T=4.49)<0.001	***	25
	10	19	85	24.55	0.005>P(T=3.46)>0.001	**	18
B ALL OCEANIC CETACEANS	2.5	22	59.66	23.21	0.02>P(T=2.57)>0.01	*	21
	5	22	60	23.30	0.02>P(T=2.57)>0.01	*	21
	7.5	22	90.34	23.97	0.002>P(T=3.77)>0.001	**	21
	10	16	84.53	23.97	0.02>P(T=2.90)>0.01	*	15
C ALL BALEEN WHALES	2.5	3	-14.77	7.1	0.2>P(T=-1.99)>0.1	NS	2
	5	3	10	22.4	P(T=0.45)<0.2	NS	2
	7.5	3	10	22.4	P(T=0.45)<0.2	NS	2
	10	1					
D PYGMY RIGHT WHALES	2.5	2	98.75	71.59	p(T=1.38)>0.2	NS	1
	5	2	96.25	73.36	P(T=1.31)>0.2	NS	1
	7.5	2	96.25	73.36	P(T=1.31)>0.2	NS	1
	10	0					

TABLE 4.7 CONTINUED

DATA SET	RADIUS	N	MEAN ±	SE (NT)	STUDENT'S T VALUE	RESULT	DF
E OCEANIC TOOTHED WHALES	2.5	19	71.32	25.9	0.02>P(T=2.75)>0.01	*	18
	5	19	67.89	26.4	0.02>P(T=2.58)>0.02	*	18
	7.5	19	103.03	26.4	0.002>P(T=3.9)>0.001	**	18
	10	15	90.33	30.5	0.02>P(T=2.96)>0.01	*	14
F SPERM WHALES	2.5	3	176.17	108.5	P(T=1.61)>0.2	NS	2
	5	3	171.67	109.6	P(T=1.28)>0.2	NS	2
	7.5	3	248.33	78.3	0.1>P(T=3.17)>0.05	NS	2
	10	3	247.5	77.6	0.1>P(T=3.19)>0.05	NS	2
G BEAKED WHALES	2.5	3	66.67	54.4	0.2>P(T=-2.12)>0.1	NS	2
	5	3	58.33	57.9	P(T=1.0)>0.2	NS	2
	7.5	3	58.33	57.9	P(T=1.0)>0.2	NS	2
	10	2	-11.25	0.9	0.05>P(T=-12.73)>0.02	*	1
H STRAP-TOOTHED WHALES	2.5	2	98.75	71.59	P(T=1.38)>0.2	NS	1
	5	2	96.25	73.36	P(T=1.31)>0.2	NS	1
	7.5	2	96.25	73.36	P(T=1.31)>0.2	NS	1
	10	1					

TABLE 4.7 CONTINUED

DATA SET	RADIUS	N	MEAN ±	SE (nT)	STUDENT'S T VALUE	RESULT	DF
I OCEANIC DELPHINIDS	2.5	13	48.65	19.3	0.05>P(T=2.34)>0.02	*	12
	5	13	46.15	19.7	0.05>P(T=2.34)>0.02	*	12
	7.5	13	79.81	22.2	0.01>P(T=3.59)>0.002	**	12
	10	10	63.5	20.9	0.02>P(T=3.06)>0.01	*	9
J LONG-FINNED PILOT WHALES	2.5	10	62.5	23.5	0.05>P(T=2.65)>0.02	*	9
	5	10	60.5	23.9	0.05>P(T=2.53)>0.02	*	9
	7.5	10	104.5	23.6	0.002>P(T=4.43)>0.001	**	9
	10	7	88.57	23.9	P(T=3.71)=0.01	**	6
K FALSE KILLER WHALES	2.5	2	2.5	3.5	P(T=0.71)>0.2	NS	1
	5	2	6.25	0.88	0.1>P(T=7.07)>0.05	NS	1
	7.5	2	5	0			
	10	2	13.75	2.65	0.2>P(T=5.19)>0.1	NS	1
L COASTAL DOLPHINS	2.5	7	57.14	37.75	0.2>P(T=1.51)>0.1	NS	6
	5	7	86.79	34.7	0.05>P(T=2.5)>0.02	*	6
	7.5	4	140.63	47.8	0.05>P(T=2.94)>0.02	*	3
	10	3	87.5	17.34	0.05>P(T=5.04)>0.2	*	2

TABLE 4.7 CONTINUED

DATA SET	RADIUS	N	MEAN ±	SE (NT)	STUDENT'S T VALUE	RESULT	DF
M COMMON DOLPHINS	2.5	4	81.25	63.18	P(T=1.29)>0.2	NS	3
	5	4	98.75	59	0.2>P(T=1.67)>0.1	NS	3
	7.5	2	182.5	83.1	P(T=2.2)>0.2	NS	1
	10	1					
N BOTTLE-NOSED DOLPHINS	2.5	3	25	7.73	0.1>P(T=3.24)>0.05	NS	2
	5	3	70.83	14.9	0.05>P(T=4.75)>0.02	*	2
	7.5	2	98.75	22.1	0.2>P(T=4.47)>0.1	NS	1
	10	2	98.75	22.1	0.2>P(T=4.47)>0.1	NS	1

NOTES:

N number of events in a data set at the stated radius, **SE** Standard Error, **DF** Degrees of Freedom (N-1)

LEVELS OF STATISTICAL SIGNIFICANCE:

* = Probability of between 0.05 and 0.01 of being equal to zero, therefore reject H_0

** = Probability of between 0.01 and 0.001 of being equal to zero, therefore reject H_0

*** = Probability of less than 0.001 of being equal to zero, therefore reject H_0.

COMPOSITION OF DATA SETS:

A. All Active Strandings - includes All Oceanic Cetaceans (B) and Coastal Dolphins (L)

B. All Oceanic Cetaceans - includes All Baleen Whales (C) and Oceanic Toothed Whales (E)

C. All Baleen Whales - includes Pygmy Right Whales (D) plus one southern right whale stranding

E. Oceanic Toothed Whales - includes Sperm Whales (F), Beaked Whales (G) and Oceanic Delphinids (I)

G Beaked Whales - includes Strap-toothed Whales (H) plus one densebeaked whale stranding

I. Oceanic Delphinids - includes Long-finned Pilot Whales (J), False Killer Whales (K) plus one unidentified delphinid stranding

L. Coastal Dolphins - includes Common Dolphins (M) and Bottle-nosed Dolphins (N)

FIGURE 4.1

The mean magnetic field deviation parameters (in nanoTesla, nT) (from equation ①) for various cetacean species and species groups as a function of distance along the coast in either direction from active stranding sites. Positives values imply that the active strandings were associated with local minima in the total geomagnetic field intensity while negative values imply that they were associated with maxima. The figures indicate the number of events involved at that radius.

LEVELS OF STATISTICAL SIGNIFICANCE:

*	=	Probability of between 0.05 and 0.01 of being equal to zero, therefore reject H_0
**	=	Probability of between 0.01 and 0.001 of being equal to zero, therefore reject H_0
***	=	Probability of less than 0.001 of being equal to zero, therefore reject H_0.

Figure 4.1A All Cetacean Strandings

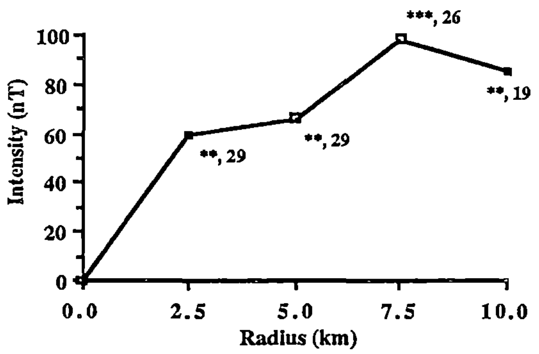


Figure 4.1B All Oceanic Whale Strandings

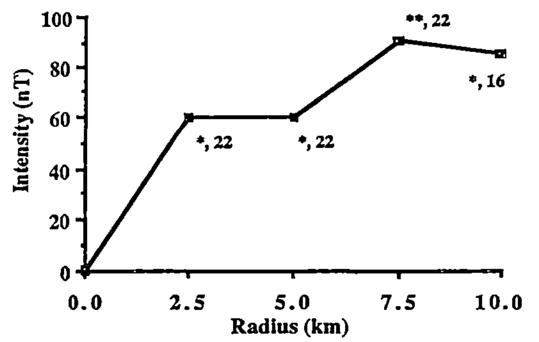


Figure 4.1C All Baleen Whale Strandings

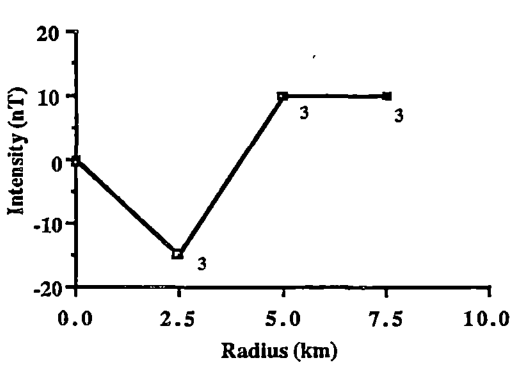


Figure 4.1D Pygmy Right Whale Strandings

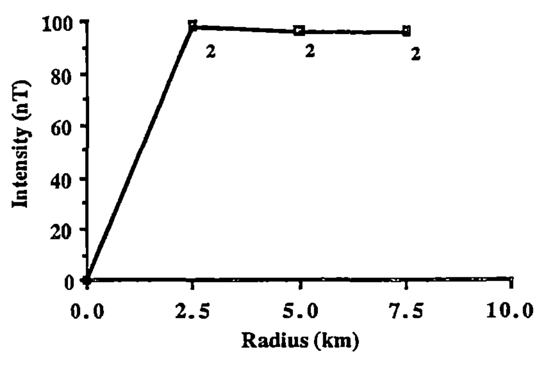


Figure 4.1E All Oceanic Toothed Whale Strandings

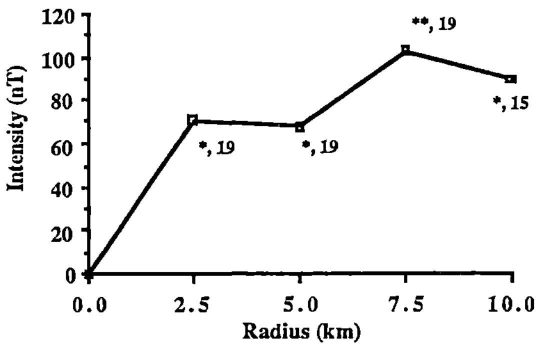


Figure 4.1F Sperm Whale Strandings

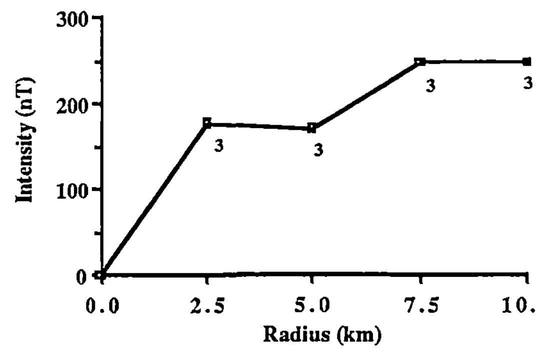


Figure 4.1G Beaked Whale Strandings

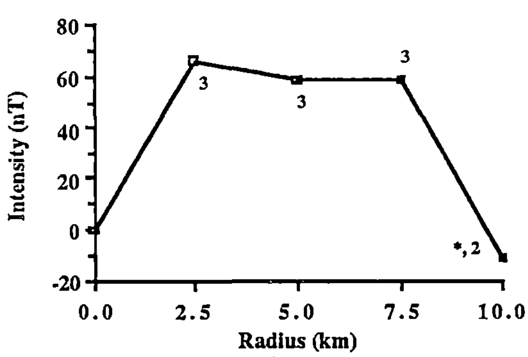


Figure 4.1H Strap-toothed Whale Strandings

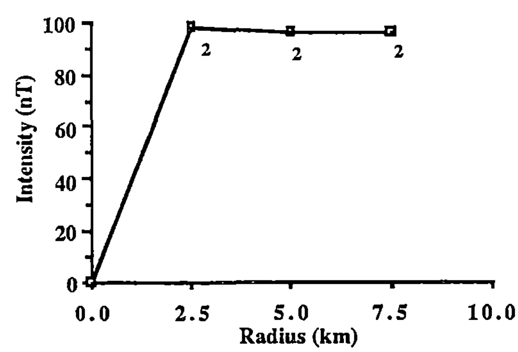


Figure 4.1I Oceanic Delphinid Strandings

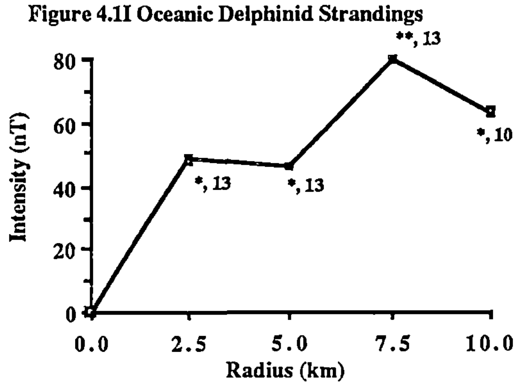


Figure 4.1J Long-finned pilot whale strandings

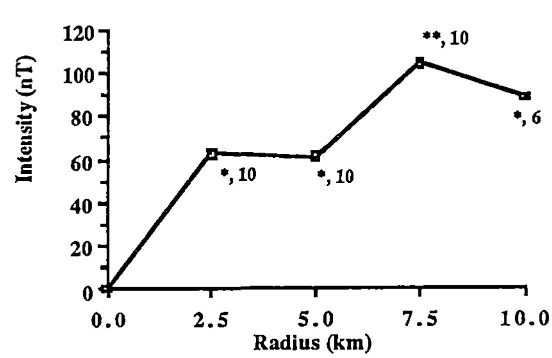


Figure 4.1K False Killer Whale Strandings

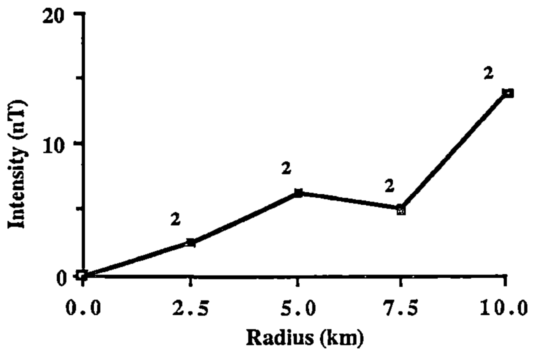


Figure 4.1L Coastal Dolphin Strandings

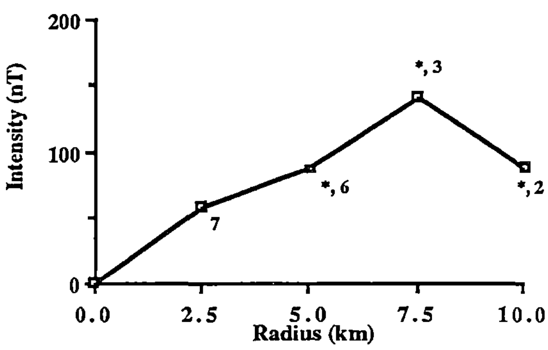


Figure 4.1M Common Dolphin Strandings

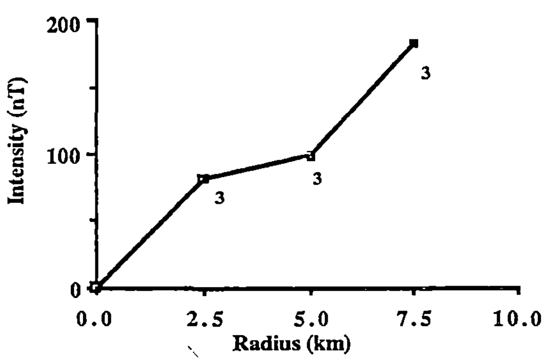
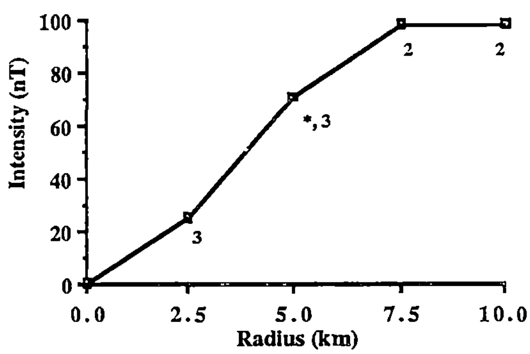


Figure 4.1N Bottle-nosed Dolphin Strandings



4.4.4.2 CONTOURS OF GEOMAGNETIC INTENSITIES

Ninety two percent of active stranding sites within the study area occur at sites where the contours of geomagnetic intensity crossed rather than ran parallel with the coast. This would indicate a strong relationship between active strandings and the alignment of the geomagnetic contours. But, if 92% of the Tasmanian coast were crossed by geomagnetic contours then the above relationship would be no more than expected. Thus, the significance of this relationship needs to be tested against the pattern of geomagnetic contours for the whole coast. Fisher's Exact Test (Zar 1974) was used to test the 2x2 tables, with the resultant probabilities for Tasmania, three coastal regions and Southeastern Tasmania being given in Table 4.8. The probabilities for the four sub-regions are presented in Table 4.9.

The lack of any significant probabilities for Tasmania or the regions leads to the acceptance of the null hypotheses, that is the probabilities of strandings occurring on sections of coast with perpendicular contours are no different from the proportions of such sites along the coastline, although there was week evidence for the rejection of the null hypothesis as the Fisher's Exact Probability for Tasmania was only just outside the 0.05 decision level. The northern section of the East Coastal Region was the only sub-region with a significant probability from the Fisher's Exact Test, however it is not possible to say whether this result represents an actual relationship or a type I statistical error.

4.4.5 DISCUSSION

Some of the findings of this study are similar to those of earlier studies (Klinowska 1985b, 1986a; Cornwell-Huston 1986; Kirschvink *et al.* 1986), with active cetacean strandings occurring at, or near, local minima geomagnetic intensity. The findings that Tasmania active stranding sites are not characterised by having contours of geomagnetic intensity cross the coast do not agree with the results of Klinowska (1985b, 1986a).

The first method used to investigate of the geomagnetic intensity at active stranding sites suffered from limitations that might prevented any trends within the data being identified. Firstly, while cetaceans may strand near local geomagnetic minima, the intensities of the local minima may vary around the mean intensity for the region. Thus the resulting pattern of intensities for stranding sites would be randomly distributed around the region's mean.

TABLE 4.8

Pattern of geomagnetic contours at active cetacean stranding sites tested against the patterns for the coast, for Tasmania, three coastal regions and Southeastern Tasmania, using Fisher's Exact Test (FET).

REGIONS	OBSERVED VALUES					PROBABILITY FROM FET	
	Stranding		No Stranding		Total		
	P	H	P	H			
Tasmania	24	2	107	32	165	P = 0.0577	accept Ho
West Coast	7	1	48	17	73	P = 0.5218	accept Ho
Storm Bay	5	0	20	3	28	P = 0.5405	accept Ho
East Coast	12	1	39	12	64	P = 0.158	accept Ho
SE Tasmania	14	0	28	5	47	P = 0.1547	accept Ho

NOTES:
SE Tasmania is a combination of the data from Storm Bay and the southern sub-region of the East Coast (see Table 4.9)
P perpendicular contours
H parallel contours

TABLE 4.9

Pattern of geomagnetic contours at active cetacean stranding sites tested against the patterns for the coast, for four sub-regions, using Fisher's Exact Test.

SUB-REGIONS	OBSERVED VALUES					PROPBABILITY FROM FISHER'S EXACT TEST	
	Stranding		No Stranding		Total		
	P	H	P	H			
Northern section of the ***West Coastal Region***							
	6	0	24	9	39	P = 0.182	accept Ho
Southern section of the ***West Coastal Region***							
	1	1	24	8	34	P = 0.9359	accept Ho
Northern section of the ***East Coastal Region***							
	3	1	31	10	45	P = 2.0974×10^{-5}	*** reject Ho
Southern section of the ***East Coastal Region***							
	9	0	8	2	19	P = 0.2632	accept Ho

NOTES:

Level of Statistical Significance
*** = Probability of less than 0.001 of a good fit, therefore reject H_0.
P perpendicular contours
H parallel contours

Secondly, geomagnetic intensities around Tasmania generally increase from the northwest to the southeast which would have overridden any trend in the stranding data. Thirdly, the numbers of active strandings around Tasmania, in particular in some of the sub-regions, were insufficient to enable any trends to be detected.

To overcome these problems Neighbourhood Analysis was used to investigate the geomagnetic intensity around active stranding sites. The results indicate that active cetacean strandings tend to occur at, or near, local geomagnetic minima at the four radii examined. Long-finned Pilot Whale (at the four radii) and Bottle-nosed Dolphin (at 5 km radius) were the only species to have significant values. Significant values were obtained when species were grouped together. Coastal Dolphins (at 5, 7.5 and 10 km radii) had significant results. Beaked Whales had a significant negative value at 10 km which might indicate that they strand near local geomagnetic maxima, however, caution is necessary due to the very small sample size involved. It is interesting to note that in Kirschvink *et al.* (1986) beaked whales also showed a tendency to strand near maxima but more work is necessary to substantiate this possibility. The combinations of Oceanic Delphinidae, Oceanic Toothed Whales and Oceanic Cetaceans had significant values at all radii. The similarities in the results for these combinations would have resulted from the high proportion of long-finned pilot whale strandings in each combination (45-77% of events).

In general, the neighbourhood analysis on the Tasmanian record agrees with the findings of Kirschvink *et al.* (1986) in that active cetacean strandings occur at, or near, local minima in the geomagnetic total field intensity. The mean geomagnetic deviations obtained in this study are often much greater than those identified by Kirschvink *et al.* (1986). These variations could have been due to differences in the geomagnetic fields and databases between Tasmania and the US. Such differences would have to be examined before any influence of variations in the behaviours of the cetaceans could be considered.

The non-significant results concerning the alignment of the geomagnetic intensity contours indicate that active cetacean strandings do not tend to occur at locations where the geomagnetic intensity contours cross, rather the proportion of the active strandings at such locations reflects the frequency of such locations around Tasmania.

These results do not agree with the findings of Klinowska's (1985b, 1986a) UK studies. This raises the question of what caused the different results. There are several possibilities, including;

a) there is a relationship in Tasmania but the statistical tests used were unable to detect it;
b) there is some differences between the geomagnetic fields of Tasmania and the UK;
c) there is some differences between the behaviours of cetaceans around Tasmanian and the UK; or
d) the relationships identified in the UK studies do not exist, rather it is an artifact of the UK stranding record, its analysis, UK geomagnetic field or a combination of these possibilities.

Until it is possible to investigate the relative importance of the above points the only course of action is to accept the null hypothesis and assume that there is no relationship between active stranding locations and the alignment of geomagnetic contours in Tasmania. An interesting difference in the patterns of geomagnetic alignment between Tasmania and the UK was the higher proportion of cells classified as being perpendicular in Tasmania (79.4%) to the UK (68%). This could be due to the smaller size and convoluted coastline of Tasmania.

Klinowska (1985b, 1986a) suggested that the loss or disruption of orientation information from the geomagnetic field immediately prior to strandings was the major contributing factor in causing strandings. Klinowska used the high level of consistency within the results from the UK strandings to support her proposal. If, however, cetaceans were stranding as the direct result of the loss of geomagnetic information then active stranding sites would be expected to be more randomly distributed with respect to geomagnetic topography. That is, if animals are stranding because of mistakes in their use of the geomagnetic field then such mistakes would cause the pattern of the strandings with regard to geomagnetic topography to be varied. Alternatively, some factors other than geomagnetic topography caused the strandings while the cetaceans where correctly using the geomagnetic topography as an orientation aid. Possible factors include disruption of monitoring the environment during periods of social upheaval or poor health reducing the abilities of cetaceans to interpret the information about an area.

In a refinement of her earlier proposals, Klinowska (1986a, 1986b) suggested that disturbances in the geomagnetic field during the 24 to 48 hours prior to active strandings may cause a loss of orientation. If such a loss occurred at some critical location then the cetaceans may eventually strand. Variation in the length of time between disturbances and subsequent strandings could be related to the distance off the UK coasts of possible critical areas in the geomagnetic topography, called "cross roads". These areas are where geomagnetic pathways appeared to branch into two or more new paths, some of which bring the cetaceans into UK coastal waters. If such a process had occurred, then it could explain the high degree of consistence concerning the geomagnetic topographies of active stranding sites.

The lack of significant results for the analysis of the contours of active stranding sites around Tasmania may indicate that disruptions of geomagnetic orientation information are occurring closer to the stranding sites than around the UK. That is, the cetaceans are not having sufficient time to regain their geomagnetic bearings, albeit the wrong ones, before they find themselves inshore where other factors, such as the oceanography and topography, add to their problems. Before this hypothesis can be considered further some of its aspects will have to be tested. Are there any relationships between active strandings around Tasmania and disturbances in the geomagnetic field? If so, can any patterns be identified from the time delay between disturbances and strandings? Then, can the time delays be related to the geomagnetic topography around Tasmania as Klinowska (1986a, 1986b) did with the UK stranding record? Such examinations can not be presently conducted due to the lack of suitable information for both strandings and geomagnetic disturbances. It should be remembered that active cetacean strandings around Tasmanian had been influenced by the intensity, if not the alignment, of the geomagnetic field.

4.5 General Discussion

The major results obtained in this examination of the factors influencing the spatial distribution of cetacean strandings are summarised below.

1. Areas with high numbers of strandings generally are characterised as being near deep oceanic water, having complex coastal topographies with resulting complex oceanographic conditions.

2. More active stranding occurred at sites with shelving topographies than at sites with steep topographies.

3. Active strandings occurred on shelving beaches with greater frequency than expected on the basis of the frequency of such topography types along the coast.

4. Active stranding sites tend to be located at, or near, local minima in the geomagnetic field but they are not characterised by being areas where the intensity contours cross the coast.

The second and third results are related to each other and they may also reflect the limitations imposed by the topography on where cetaceans can strand. That is, animals are not able to strand on sheer cliffs, or if they do, they tend not to remain ashore long enough to be discovered.

From the above summary it appears that the locations of cetacean strandings around Tasmania have been influenced by various features of the physical environment. The particular features include the relative complexity of oceanographic conditions and coastal topography (which are inter-related); the frequency of shelving coastal topographies along the coast, although it is not clear whether this is because strandings can only occur on these types of topographies or whether they cause the strandings; and the distribution of local minima in the geomagnetic topography. In general, these results are in agreement with the predictions of this study's working hypothesis.

A general scenario for how these features might have influenced the location of the strandings around Tasmania for oceanic cetaceans is that for some reason these animals have come into the inshore area. While in the nearshore area, the cetaceans use the local geomagnetic topography as a source of orientation: some of these cetaceans experience difficulties coping with the combination of oceanographic conditions and coastal topographies in the nearshore environment with the result that a few animals become stranded. The cetaceans have greater difficulty in areas with more complex oceanography and coastal topographies.

The level of experience of oceanic cetaceans at handling the coastal area and its conditions is likely to be an important influence in whether or not a particular cetacean might strand. For cetaceans in the open ocean, major orientation errors may have no long term impact whereas even minor errors in the nearshore area can be fatal. In addition, coastal oceanographic conditions are generally more complex and of shorter durations than conditions in the open ocean. Other contributing factors include the health status of the animals plus the existence of any social activities or disruptions that might prevent animals from fully monitoring their environment.

For coastal species the situation is different in that they have a higher level of experience at handling the coastal area and its conditions. In this context it is worth noting that two of the four cetacean species that are known to frequent Tasmanian coastal waters have very low stranding frequencies, being the southern right whale and killer whale. The other two species, common and bottle-nosed dolphins, are more numerous around Tasmania, which, in part, explains their higher stranding frequencies simply on the basis of their greater availability to strand. The coastal dolphins do appear to strand as the result of errors relating to both oceanographic conditions (strandings on tidal flats) and geomagnetic topography, thus factors that affect oceanic species can still influence coastal species.

Returning to the issue of what factor(s) induced oceanic species to enter coastal waters in the first instance, it appears, from the available literature on cetacean ecology that variations in food supply are the major factors in determining the distribution and movements of the cetaceans. Therefore, if stranding rates are related (directly or indirectly) to the availability of cetaceans then it may be possible to relate fluctuations in stranding rates with variations in important indicators of the Tasmanian marine ecosystem. The susceptibility of cetaceans to strand, that is their health or social circumstances, also vary with fluctuations in the intensity of environmental factors. The investigation of these issues is the topic of the next chapter.

CHAPTER 5: SEASONAL AND ANNUAL VARIATIONS IN THE TASMANIAN CETACEAN STRANDING RECORD

5.1 INTRODUCTION

In Section 3.3 it was shown that the number of active strandings reported around Tasmania have increased over the years, with some variation between years (Fig. 5.1), and during the year the number of active strandings peak during the summer (Fig. 5.2). Some proportion of these variations can be attributed to changes in observer effort, however, there are indications that other factors have influenced the numbers of strandings. The pattern of peaks and lows in the numbers of strandings between years is likely to be a reflection of differences in the actual rate of strandings. The variation in the actual stranding rate in the seasonal pattern is indicated by the continuation of the summer peak for herd strandings (Fig. 5.3) since herd strandings are generally conspicuous, therefore less affected by observer effort.

Variations in the seasonal and annual stranding rates have been reported from other parts of the world (Mitchell 1968; Mead 1979; Sheldrick 1979; Baker 1981a; Easton *et al.* 1982). Explanations have ranged from that the variations are due to fluctuations in the density dependent mortality rate of cetacean populations off the respective coasts (Sergeant 1979, 1982), to seasonal, or long-term fluctuations in oceanography (Sheldrick 1979; Easton *et al.* 1982). Observer effort was recognised as an important component in some patterns (Mead 1979; Baker 1981a; Easton *et al.* 1982).

The working hypothesis being examined in this study proposes that if the rate of strandings has been influenced by variations in the physical environment than the stranding rate should correlate with changes in the intensity of such features. This chapter will investigate whether any correlations exist between variations in Tasmanian environmental features and the stranding record. Explanations of how the features might have influenced seasonal and annual patterns of strandings will then be explored.

Physical features might influence the stranding rate by either altering the availability of animals or by changing their susceptibility to strand. The two mechanisms are not necessarily mutually exclusive and could operate in combination. Fluctuations in environmental features may effect cetaceans differently, oceanic species may react differently to coastal species while baleen

Figure 5.1

Number of Active Cetacean Strandings reported per year

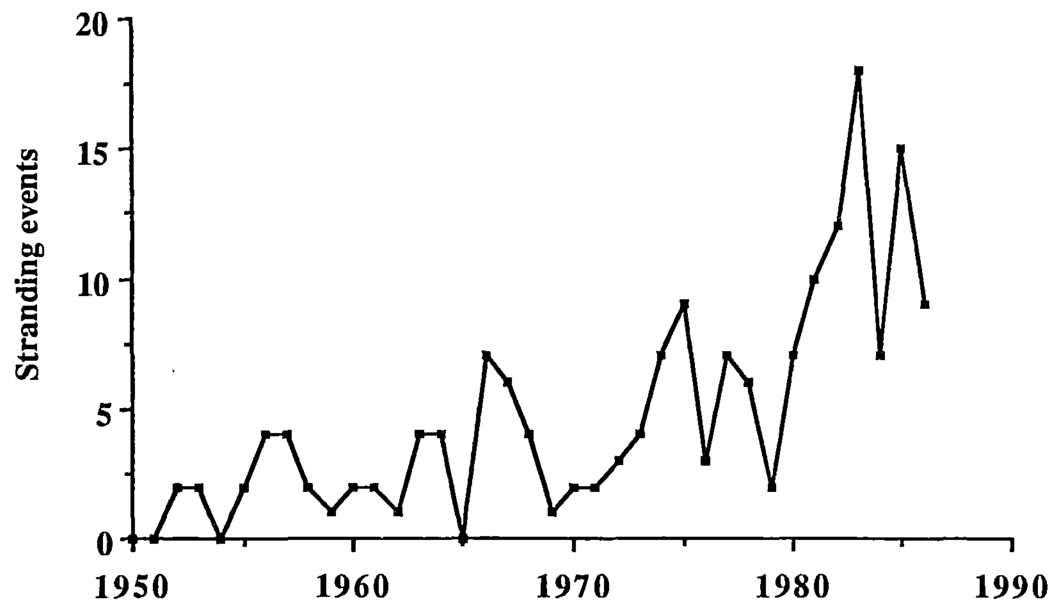


Figure 5.2

Number of Active Cetacean Strandings reported per Month

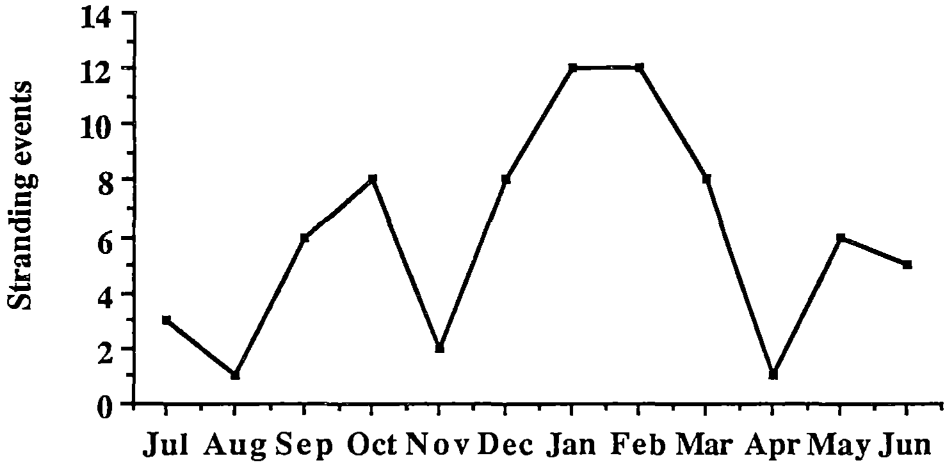
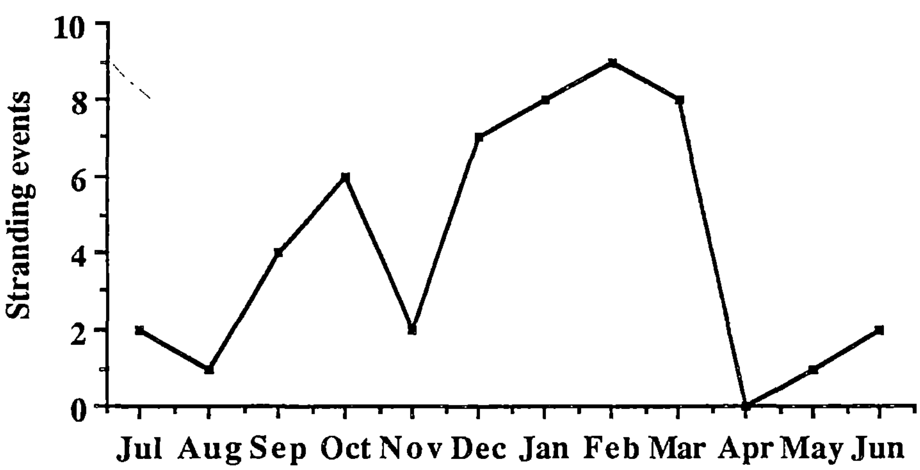


Figure 5.3

Number of Herd Strandings reported per month



whales may respond differently to toothed cetaceans. Another important variable is the delay between the fluctuations in the environmental factor and any changes in stranding rate. For example, fluctuations that affect the orientation of cetaceans, such as storms or disruptions of the magnetic field, the effect would be almost immediate (a matter of hours or days) while changes in the distribution of cetaceans may take months before effects are detected.

The most likely physical features to influence the rate of strandings are weather, oceanographic conditions and disruption of the geomagnetic field. Unfortunately, data about the state of the environment before and during specific stranding events are around Tasmania not available, however, data on the seasonal and annual patterns for several factors are available for comparison with the stranding records of several species and species groups.

5.2 SEASONAL VARIATIONS

5.2.1 INTRODUCTION

Seasonal variations in the Tasmanian environment include alterations in atmospheric and oceanic circulation patterns (Rochford 1975; Harris *et al.* 1987). Most features reach their maximum during the summer or winter, however, a few features peak during autumn and spring. These latter features are usually related to the equinoxes and include the frequency and intensity of southerly gales, the size of the spring-neap tidal range (Beer 1983), and the frequency and intensity of geomagnetic disturbances (Thompson 1985). Seasonal variations are predictable in their occurrence, if not their intensity. This predictability means organisms, including cetaceans, have evolved mechanisms and behaviours to cope with, and even take advantage of, these patterns (Brown 1976a, 1976b; Gaskin 1982; Klinowska 1986d).

Some cetacean species show strong variations in their distribution with the seasons (Gaskin 1982; Evans 1987). The most obvious patterns are the long range migrations undertaken by baleen whales between summer feeding grounds in polar waters and winter breeding areas in temperate or tropical seas. Less is known about migration patterns in toothed cetaceans, although, a wide range of strategies have been identified. Some species, such as beaked whales, range from polar to tropical waters but it is not known whether these animals undertake long range migrations, occur throughout their full range all year round, or use a strategy somewhere in between these two extremes (Gaskin 1982). Sperm whales display a variety of migration strategies depending on the age and sex of the individuals (Best 1979; Gaskin 1982). Small toothed cetaceans in temperate and sub-tropical areas undertake limited north-south movements. Cetaceans in the tropics and sub-tropics tend to undertake movements between inshore and offshore waters with the seasons (Gaskin 1982; Evans 1987).

Cetaceans also vary their activity patterns with the seasons. Again, baleen whales display the strongest pattern with marked divisions of the year into breeding and feeding periods. Some toothed cetaceans change their major prey species during the year, often corresponding to changes in the cetaceans' distribution (Gaskin 1982). Seasonal cycles could influence patterns of strandings by altering either the availability or susceptibility of cetaceans to strand. Seasonal changes in the distribution of cetaceans are obvious examples of the former. These changes are often related to variations in oceanography and climate. Loss of orientation information caused by disruptions of the geomagnetic field (Klinowska 1985b, 1986a) is an example of the latter influence.

This section investigates whether seasonal patterns in oceanographic features or magnetic disruptions can explain the seasonal pattern in strandings around Tasmania. Unfortunately, data describing micro-scale oceanographic features around Tasmania are not available, however overall seasonal patterns are available for some features, including mean monthly sea surface temperature (SST), salinity, and the number of geomagnetically disturbed days per month.

5.2.2 METHOD

5.2.2.1 STRANDINGS

More strandings are reported during the summer months, partly due to higher levels of observer effort at that time of the year. The levels of observer effort has varied over the years but the influence of these variations are reduced because strandings data from the past 70 years, have been combined therefore only monthly variations remain.

Active strandings have been used, ~~were~~ where possible, for the analysis involving all species and herd strandings because they are less affected by observer effort than events of undetermined health status, plus aspects of the physical environment could have influenced, or caused, these events. In addition, information on the actual date of stranding are generally better known for active stranding than for the rest of the record. In the comparisons involving individual species it has been necessary to use all stranding events (except known passive events) because of the lack of data. This reduces the confidence that can be placed in the results but indications can still be gained into which of the oceanographic features are worth of further examinations.

The following species and species group had both significant seasonal pattern in their stranding record and sufficient data to enable useful comparisons to be made: Sperm Whales, Common Dolphins, Long-finned Pilot Whales and Herd Strandings (see Section 3.3 and 5.2.2.4).

5.2.2 OCEANOGRAPHIC CONDITIONS

A general outline of the patterns and seasonal changes in Tasmania's oceanography can be found in Rochford (1975), Nicol (1985) and Harris *et al.* (1987).

The seasonal patterns are summarised below.

1. Water masses and their circulation generally shift south during the summer and north in the winter (similar shifts occur in the atmosphere). These shifts result in changes in the physical and chemical properties of the seas off Tasmania. The main water masses are; the East Australian Current (warm, high in salinity), the central Tasman Sea (warm, high in salinity) and Sub-Antarctic Water (cold, low in salinity). There is also some cold highly saline water which leaves Bass Strait during the winter and enters northeastern Tasmanian coastal waters. The colder southern waters have higher concentrations of oxygen and dissolved nutrients, although the actual levels are still very small.

2. Surface temperatures for both inshore and offshore waters decrease in winter to a minimum during August then rise to a maximum during February (Fig. 5.4).

3. Salinity levels follow a similar pattern to temperature, with a minimum around November and a maximum around March (Fig. 5.5). Again, offshore waters show a similar pattern to inshore waters.

4. The major summer circulation features off the east coast are occasional intrusions of warm eddies from the East Australian Current and variations in the northern boundary of the Sub-Tropical Convergence Zone off the south east of Tasmania. Off the west coast there is a northwesterly flow inshore and southeasterly flow offshore (the latter flow is very narrow in cross section; Baines *et al.* 1983). During the winter, the main circulation pattern is from the northwest through Bass Strait and down the west coast around southern Tasmania. There are occasional intrusions of cold subantarctic waters into southeastern Tasmania.

5. Other oceanographic processes will show seasonal variations but published data for Tasmania are not available. The processes include increased mixing of surface waters

Figure 5.4

Maximum Sea Surface Temperature off Maria Island
(data from Rochford 1975)

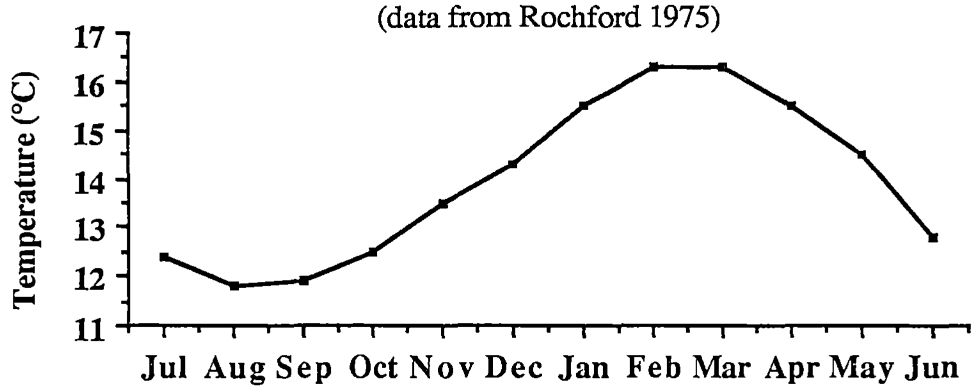


Figure 5.5

Average Salinity per Month (data from Rochford 1975)

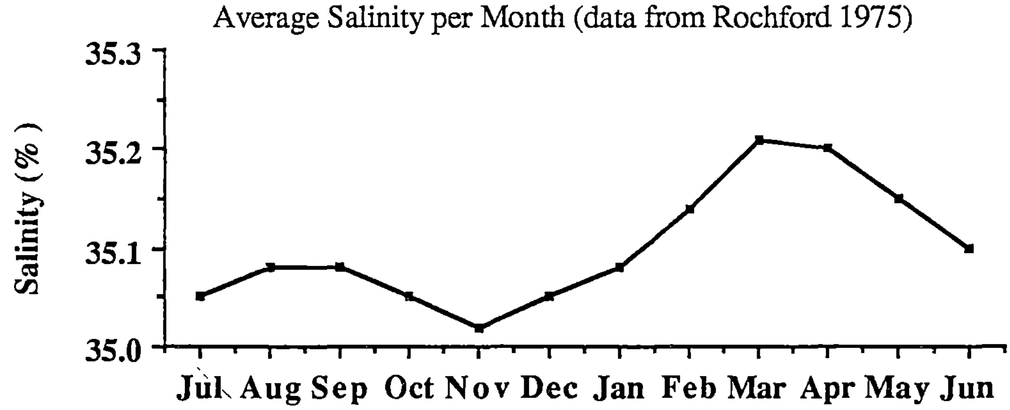
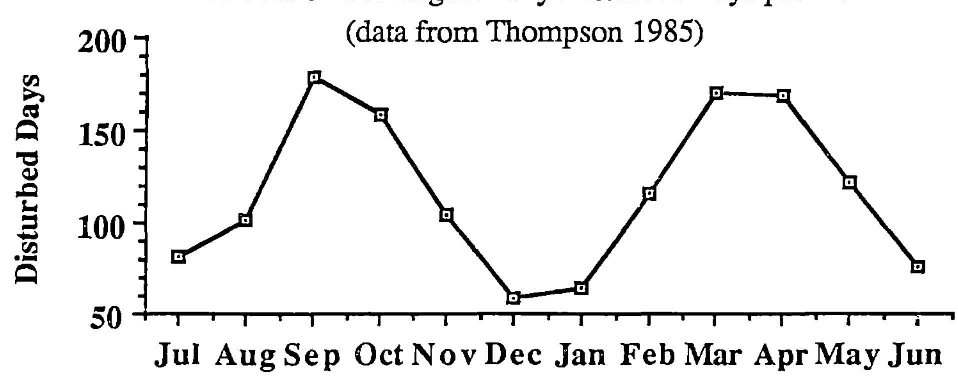


Figure 5.6

Number of Geomagnetically Disturbed Days per month
(data from Thompson 1985)



due to late winter and spring gales, and increased primary productivity during summer and early autumn, with subsequent increases at higher trophic levels (Harris *et al.* 1987).

The data for averaged monthly sea surface temperature and salinity come from the CSIRO oceanographic station off Maria Island, on the Tasmanian east coast, for the years 1945 to 1972 Rochford (1975).

5.2.2.3 GEOMAGNETIC DISTURBANCES

The data on the monthly frequencies of geomagnetic disturbances are from the Ionosphere Prediction Service of the Australian Department of Science and covers the years 1932 to 1983 (Fig. 5.6) (Thompson 1985). The cyclic nature of the number of magnetically disturbed days and how they arise from solar activities are described in Thompson (1985).

Thompson (1985) uses the A index as the measure of magnetic disturbance which he defines as:

> "...a daily disturbance index which is derived from the average of the eight 3 hour K indices..." (Thompson 1985),

and where the K index is defined as:

> "...a 3-hourly quasi-logarithmic index of the degree of geomagnetic disturbance relative to the known quiet day variation...ranges from a value of 0 (very quiet) to a value of 9 (very disturbed)." (Thompson 1985).

Parkinson (1983) stated that the A index is directly proportional to the range of magnetic disturbance not its logarithm as is the case with the K index. Both scales are defined for each magnetic observatory. Thompson (1985) used a global or planetary A index, denoted by "A_p", which is the average of A values obtained from a world-wide standard network of magnetic observatories. The establishment of a minimum level of magnetic disturbance is important as most days have some degree of magnetic disturbance. The minimum level used in Thompson (1985) for the monthly frequencies is 36 A_p.

5.2.2.4 STATISTICAL METHODS

The stranding frequencies have been compared against their means to see if they displayed seasonal patterns rather then being the result of chance. The patterns were tested using the Chi-squared Goodness-of-fit test (Snedecor and Cochran 1980). The stranding frequencies where clumped into 3 month groups to provide adequate cell size for the analysis.

Relationships between the various physical features and the different stranding records were identified using linear regressions and tested for significances using correlation coefficients (Snedecor and Cochran 1980). These calculations were performed by the "CRICKET GRAPH" graphics and statistical computer programme (Rafferty and Norling 1986).

5.2.3 RESULTS

5.2.3.1 STRANDINGS

The number of active strandings reported each month (Fig. 5.2) shows a strong peak during the summer months, with a highly significant Chi-squared value ($0.001>P(\chi^2 = 16.44)$). A similar pattern occurs with herd strandings (Fig. 5.3), also having a highly significant Chi-squared value ($0.001>P(\chi 2 = 22.64)$). The similarities between these patterns is hardly surprising as herd strandings are a major component of active strandings.

The monthly stranding frequencies for the three species examined here are summarised below:

SPERM WHALES strandings (Fig. 5.7) mainly occur from January to March ($0.05>P(\chi^2 = 9.79)>0.01$, df = 3).

COMMON DOLPHINS strandings (Fig. 5.8) show a marked peak from December to February ($0.05>P(\chi^2 = 11)>0.01$, df = 3)

LONG-FINNED PILOT WHALES, strandings per month (Fig. 5.9) show some seasonality, with more events reported in summer and early autumn ($0.05>P(\chi^2 = 10)>0.01$, df = 3).

The seasonal patterns of the other species in the Tasmanian record are discussed during the summaries of their stranding records (Section 3.2.3).

Figure 5.7

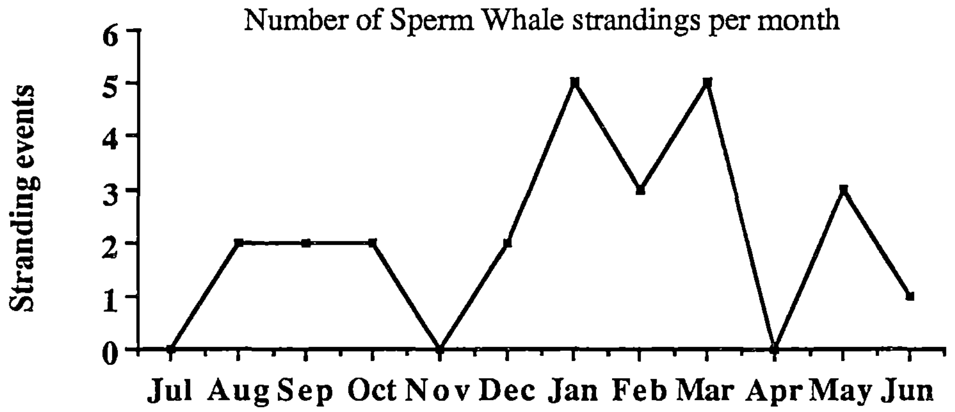
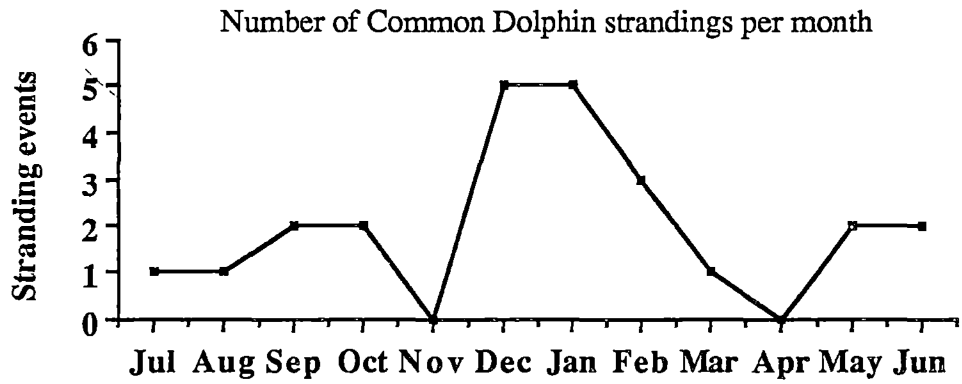


Figure 5.8



5.2.3.2 Oceanographic Conditions

Sea Surface Temperature (SST)

Monthly totals of active strandings (Fig. 5.2) show an initial similarity with average SST (Fig. 5.4), with both peaking during the summer but these patterns are not significantly correlated ($0.1>P(r = 0.52)>0.05$, df = 10). The only significant correlations with SST was the long-finned pilot whale (positive) (Fig. 5.10) ($0.5>P(r = 0.63)>0.01$; df = 10). This result needs to be treated with some caution as the SST data are averages while the stranding data are accumulative; nevertheless, the results are interesting and informative.

Salinity

When combined, all active strandings were not significantly correlated with salinity ($r = 0.08$). Similar results were obtained for comparisons between species and herd strandings with salinity.

5.2.3.3 Geomagnetic Disturbances

The comparison of active strandings with the number of magnetically disturbed days per month initially appeared to indicate a negative relationship between the two patterns, however, the correlation coefficient was not significant ($r = 0.13$), therefore, there is no linear relationship. Non-significant results were also obtained from the comparisons between species and herd strandings data and geomagnetic disturbed days.

5.2.4 Discussion

Active and herd strandings both peak during the summer. No particular species could be identified as the major contributor to these patterns. The only significant correlation between the stranding data and the oceanographic conditions was long-finned pilot whales with sea temperature (Fig. 5.10). This correlation may indicate that the distribution of long-finned pilot whales are influenced by sea surface temperatures such that long-finned pilot whales are more common off Tasmania during the summer, increasing their availability to strand. These whales could be moving such that they remain within a preferred temperature range. Alternatively,

Figure 5.9

Numbers of Long-finned Pilot Whale strandings per month

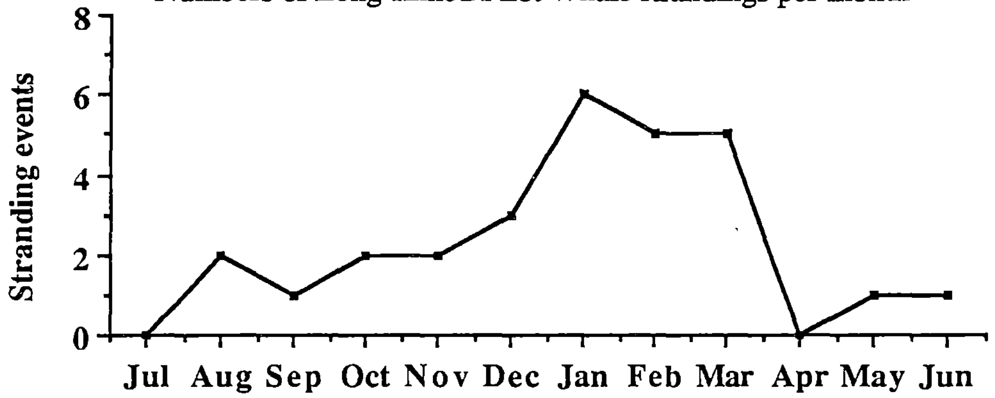
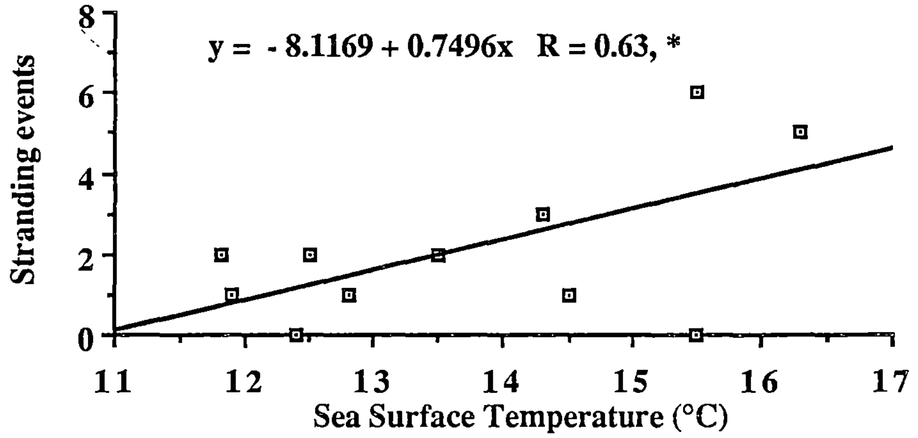


Figure 5.10

Comparison of Long-finned Pilot whale strandings
against average Sea Surface Temperature



changes in the Tasmanian marine ecosystem due to the seasonal patterns may be leading to greater numbers of long-finned pilot whales being inshore during the summer.

The lack of significant correlations between the stranding data and salinity was not unexpected since marine cetaceans do not have very narrow salinity requirements (Gaskin 1982, 1986; Evans 1987). The absence of significant correlations with geomagnetic disturbances does not appear to support Klinowska"s (1986a, 1986b) hypothesis that cetacean strandings are due to disruptions of their geomagnetic navigation, however, the important feature of the seasonal cycle of magnetic disturbances is its very predictable nature. If, like other seasonal cycles, cetaceans can allow for the increased frequency of magnetic disturbances during the equinoxes then the rare and unpredictable disturbances that occurred during summer or winter months may actually cause greater problems for cetaceans. If combined with increased availability of animals during either the summer, this could contribute to the seasonality peaks in stranding rates.

The general lack of relationships between the stranding frequencies of various cetacean species or species groups with the three environmental features suggests that seasonal variations in the rate of strandings cannot be explained by any single environmental feature. The influence of observer effort may have not been completely removed from the data.

The following hypothesis can be proposed for the seasonal pattern of active strandings around Tasmania. It involves the influences of environmental factors and observer effort. Cetaceans within Tasmanian coastal waters, undertake seasonal movements which effect their availability to strand. The occurrence of cetaceans increase with either warmer temperatures, as might be the case with long-finned pilot whales, or with colder temperatures, as with the baleen whales. These patterns need not be caused by temperature since changes in sea temperature are indicative of, and sometimes cause, other changes in the marine environment (Rochford 1975; Harris *et al.* 1987).

The susceptibility of cetaceans to strand is affected by both the location of the cetaceans and the frequency of unusual environmental events. Loss of orientation information or disruption to food supply by unpredictable events, such as magnetic disturbances or serve weather would have greater impact when cetaceans are near Tasmania and when such events are unexpected.

Information needed to test this hypothesis includes sighting records for cetaceans around Tasmanian and data on the oceanographic, weather and geomagnetic conditions for individual strandings. The first data set is to determine whether the abundances of cetaceans varies seasonally. The second data set is to detect whether unusual rather than regular events can be correlated to cetacean strandings.

5.3 ANNUAL VARIATIONS

5.3.1 INTRODUCTION

Reports of cetacean strandings have increased over the years, particularly the past two decades (Fig. 5.1). It is unlikely that this increase can be explained by an increase in the rate of strandings, rather observer effort around Tasmania has increased and would be the major influence (Section 3.4). It is likely that there are more strandings occurring each year than are reported (Mead 1979; Sheldrick 1979). Nevertheless, fluctuations in reports of strandings between neighbouring years, particularly for active events, can be assumed to reflect actual variations in the stranding rates. If this assumption is correct, then some factors in the Tasmanian marine environment have affected stranding rates. Again, the influences could be direct on the cetaceans or indirect via effects within the ecosystem.

Tasmanian cetacean strandings will be examined for influences of various environmental factors. Suggestions of possible mechanisms for how these features affected stranding rates will be developed in light of the results. Features known to influence the distribution and abundance of cetaceans, such as aspects of oceanographic and climatic patterns (Gaskin 1982) will be examined in this study. A recent examination of the influences of climate and oceanography on the productivity of Tasmania's freshwater and marine ecosystems (Harris *et al.* 1988) identified several environmental features worth examining in this study. In addition, the influence of disruptions to the geomagnetic field will be examined. A comparison between the various climatic and oceanographic features will be carried out to develop an overall picture of the dynamics of the Tasmania marine environment.

5.3.2 METHOD

5.3.2.1 STRANDINGS

Several restrictions were applied to the Tasmanian stranding record to develop data bases suitable for used in the following analyses.

1. Stranding reports prior to 1950 have not been included due to their rarity.

2. Data have been restricted to active events for the reasons outlined in Chapter 4.

3. Impacts of variations in observer effort over the years were removed, or at least reduced, by the use of an index of stranding frequencies rather that the reported rate of strandings. The index is derived by calculating the mean for ten year blocks and then subtracting the mean from the observed frequencies. The index represents the variation of the strandings rates about the mean.

The stranding index was calculated for all cetacean species (Fig. 5.11) and for several sets of stranding data, including:

a) single species; Sperm Whales (Fig. 5.12), False Killer Whales (Fig. 5.13), Long-finned Pilot Whales (Fig. 5.14), Common Dolphins (Fig. 5.15), Bottle-nosed Dolphins (Fig. 5.16) and Pygmy Right Whales (Fig. 5.17), and

b) combinations of various species; Beaked Whales (Fig. 5.18), Coastal Dolphins (Fig. 5.19), a combination of common and bottle-nosed dolphins, and Oceanic Toothed Whales (Fig. 5.20), a combination of sperm, false killer, long-finned pilot, and beaked whales.

The species involved in the combinations were grouped together because they generally have similar ecologies and habitats. Beaked whales are solitary oceanic species (Gaskin 1982). The two dolphin species in "Coastal Dolphins" both frequent Tasmania's coastal waters (Guiler 1978; McManus *et al.* 1984). The species in "Oceanic Toothed Whales" generally occur in oceanic waters, rarely coming inshore (Watson 1981; Gaskin 1982), therefore, this combination is the antithesis of "Coastal Dolphins".

5.3.2.2 Climatological and Oceanographic Features

Seven environmental features that either indicate, or determine, the state of the Tasmanian marine environment are used in this investigation. The data came from Harris *et al.* (1988) and their derivations are described there so only general outlines are given here.

Figure 5.11

Stranding Index for All Cetacean

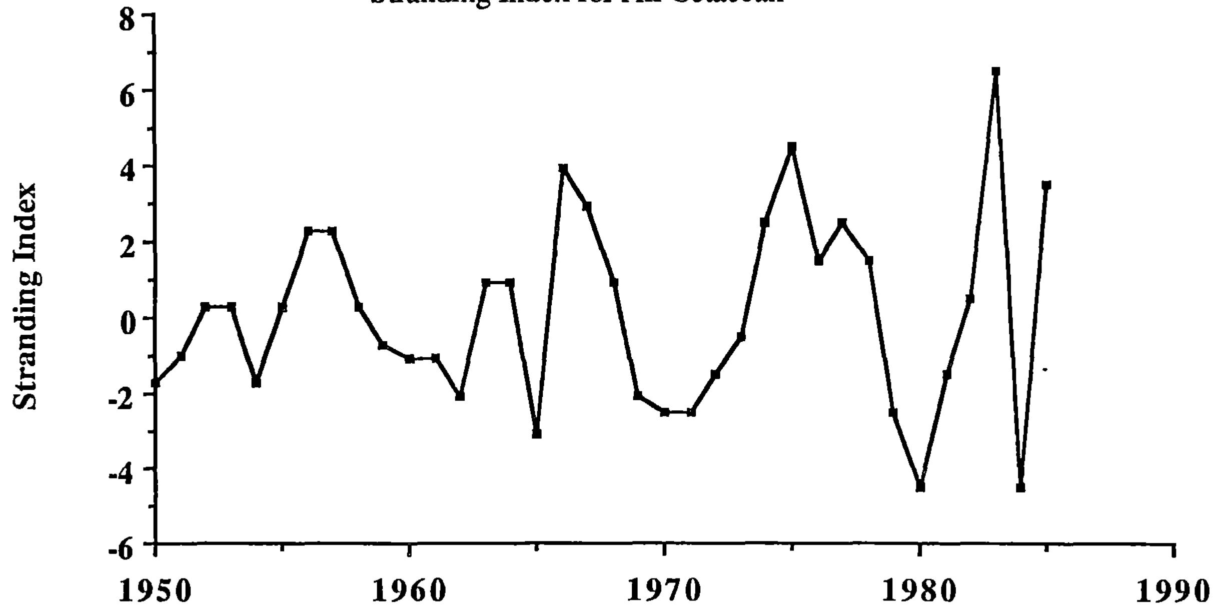


Figure 5.12

Stranding Index of Sperm Whales

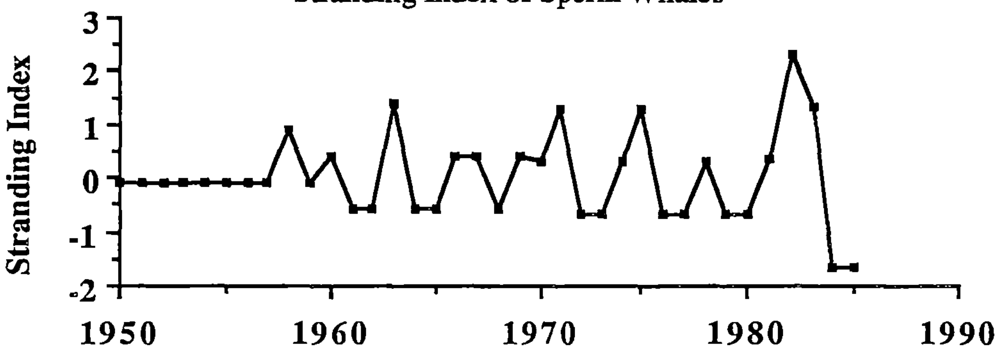


Figure 5.13

Stranding Index of False Killer Whales

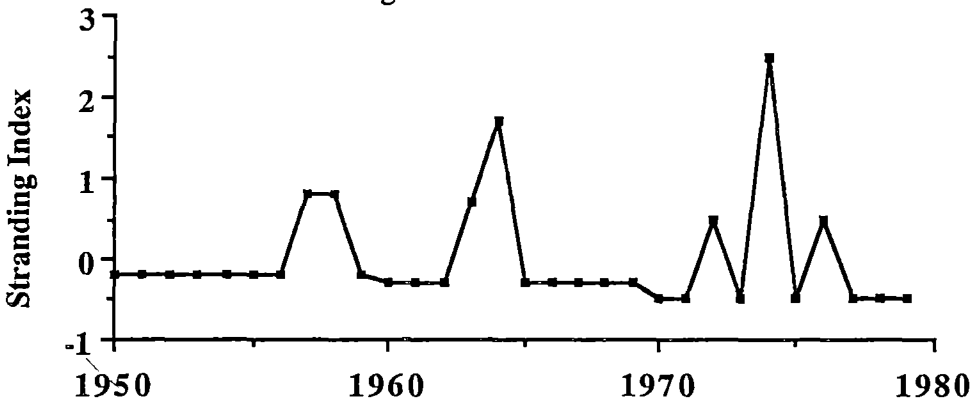


Figure 5.14

Stranding Index of Long-finned Pilot Whale

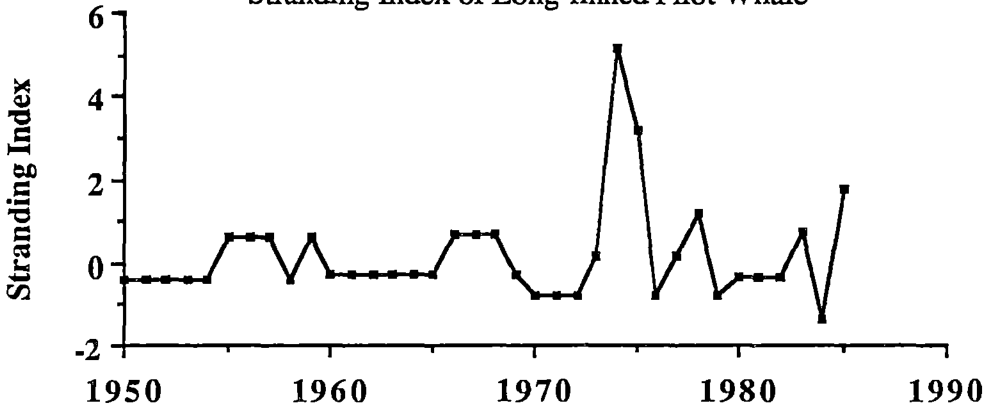


Figure 5.15

Stranding Index of Common Dolphin

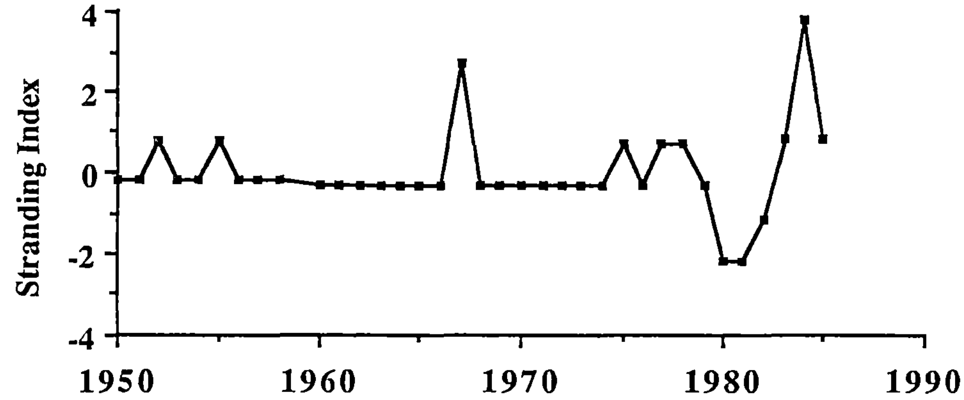


Figure 5.16

Stranding Index of Bottle-nosed Dolphins

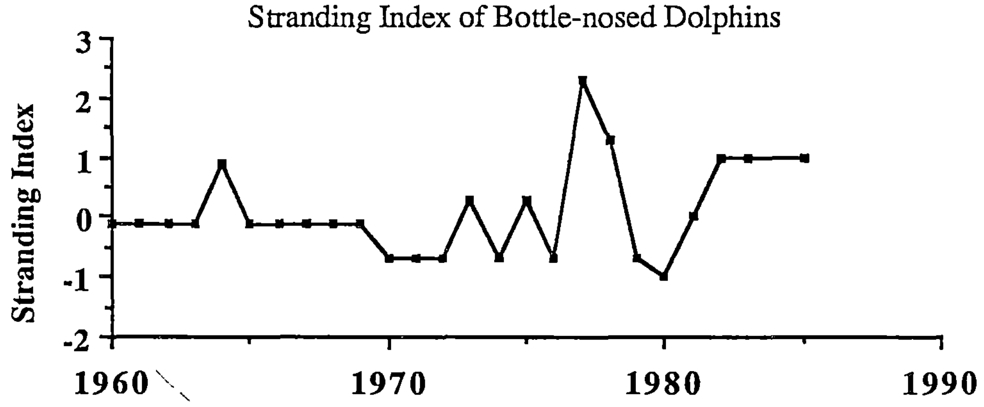


Figure 5.17

Stranding Index of Pygmy Right Whales

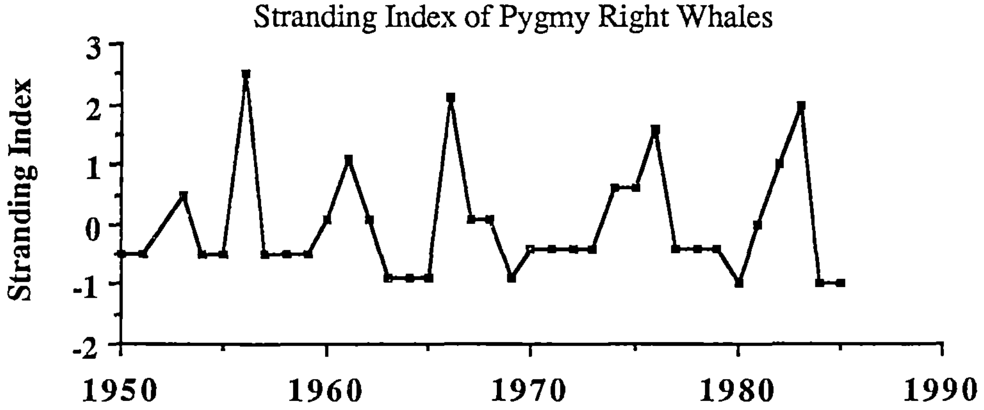


Figure 5.18

Stranding Index of Beaked Whales

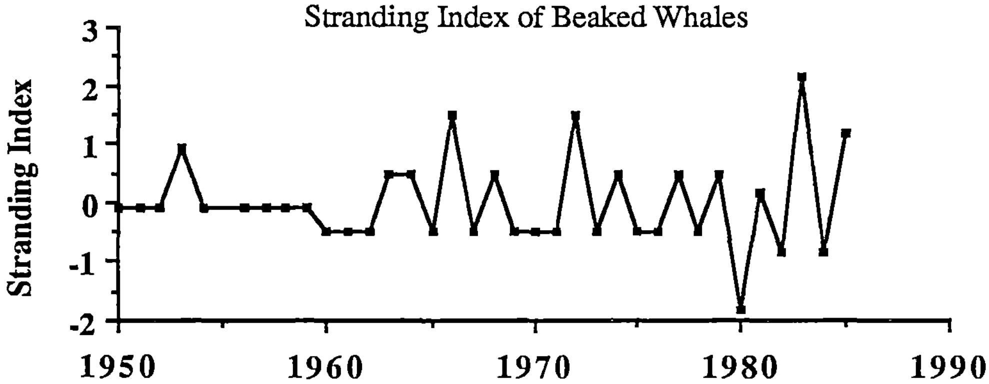


Figure 5.19

Stranding Index of Coastal Dolphins

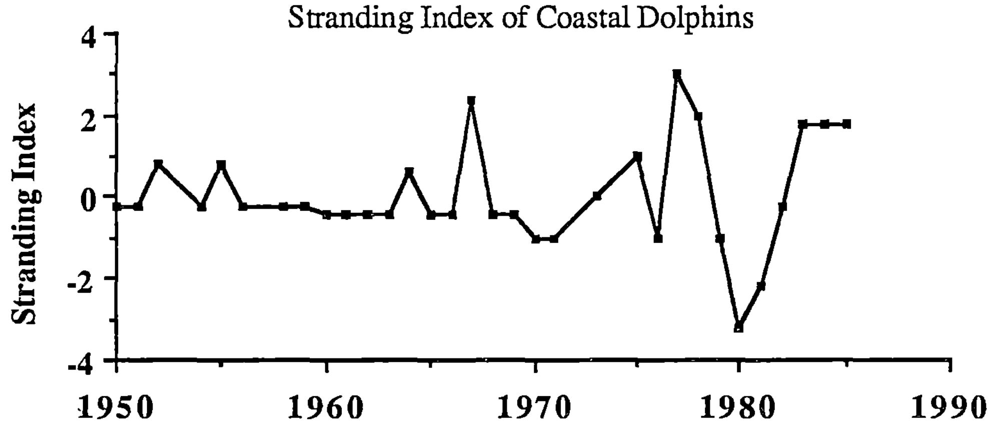
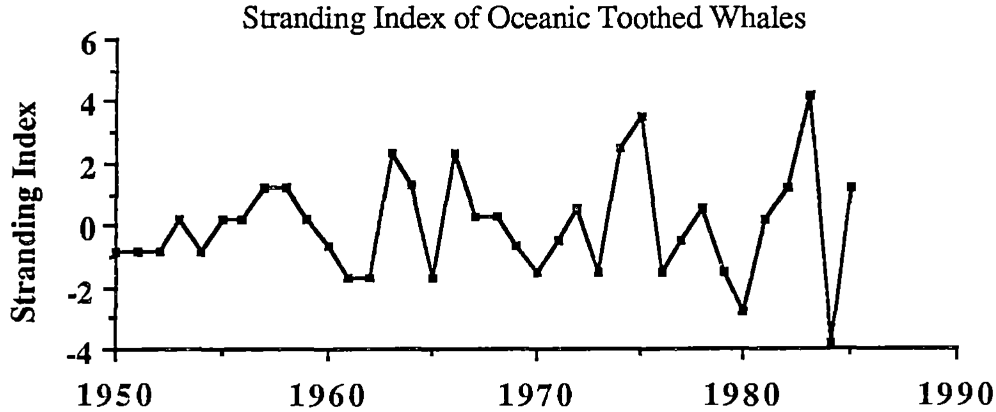


Figure 5.20

Stranding Index of Oceanic Toothed Whales



The seven environmental features are:

i) AIR PRESSURE OVER HOBART (AP Hobart) (Fig. 5.21), average annual air pressure recorded in Hobart. Hobart's air pressure and Tasmania's weather are directly related as periods of high pressure are characterised by warm, stable weather while low pressures are associated with cold, wet and unstable weather.

ii) AIR PRESSURE OVER MACQUARIE ISLAND (AP Macq Is) (Fig. 5.22), a measure of the weather over Macquarie Island, 1000 km southeast of Tasmania, and immediately north of the Antarctic Convergence Zone. Weather around Macquarie Island is an indicator of the weather near the Antarctic Convergence Zone, an area of heightened biological activity (Gaskin 1982).

iii) AIR PRESSURE DIFFERENCES BETWEEN HOBART AND MACQUARIE ISLAND (AP Diff) (Fig. 5.23), a measure of the pressure gradient between Tasmania and Macquarie Island, which is a significant section of the pressure gradient from the tropics to the Antarctica. Shifts in this gradient cause changes in the weather around Macquire Island and Tasmania. It is also a section of ocean that cetaceans pass through when migrating between the Antarctic and the temperate/tropical regions off Australia.

iv) ZONAL WESTERLY WINDS (ZWW) (Fig. 5.24) consist of the number of days per year when westerly winds exceed a minimum speed (Harris *et al.* 1988). ZWW are a major feature from 40°S to 60°S and for Tasmania's weather. Years with frequent westerly winds (i.e. high ZWW) are associated with cold, wet and unsettled weather. ZWW fluctuate through a 10-11 year cycle in intensity (Harris *et al.* 1988)

v) SOUTHERN OSCILLATION INDEX (SOI) (Fig. 5.25) is the difference in the air pressure between Darwin and Tahiti. The index indicates the existence of large scale oscillations in oceanic and atmospheric circulations in the tropical Pacific. Warm events, known as El Niño/Southern Oscillation (ENSO), are indicated by low values while cool events have high values (Bradley *et al.* 1987). Southern Oscillation events may originate in fluctuations in the atmospheric and oceanic circulations in the region off southern Australia across to western New Zealand, therefore, SOI may indicate changes in the marine environment around Tasmania a year or two before the changes are actually seen in the SOI (Harris *et al.* 1987, 1988).

Figure 5.21

Annual Average Air Pressure over Hobart
(data from Harris et al. 1988)

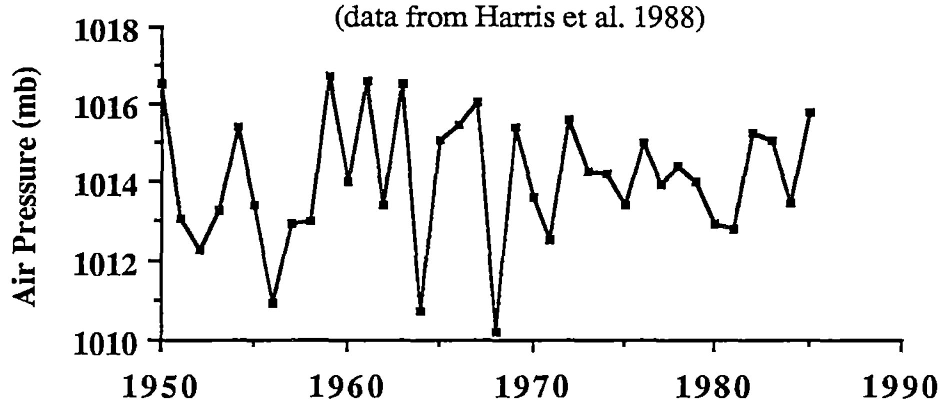


Figure 5.22

Average Annual Air Pressure over Macquarie Island
(data from Harris et al. 1988)

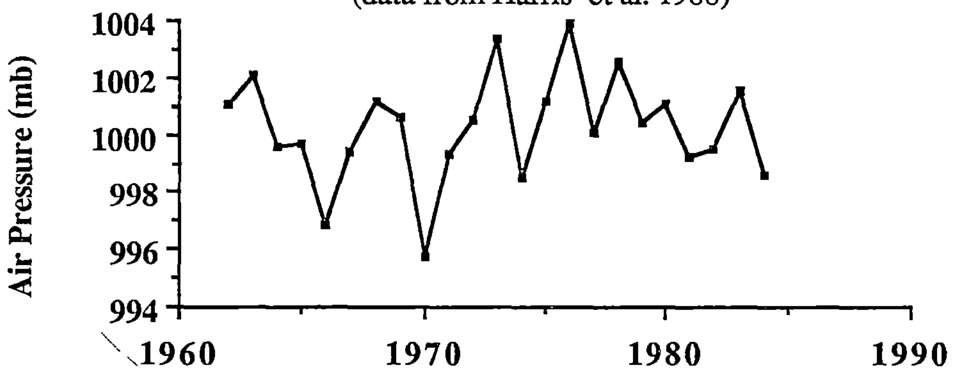


Figure 5.23

Differences in Average Annual Air Pressure over Hobart
and Macquarie Island (data from Harris et al. 1988)

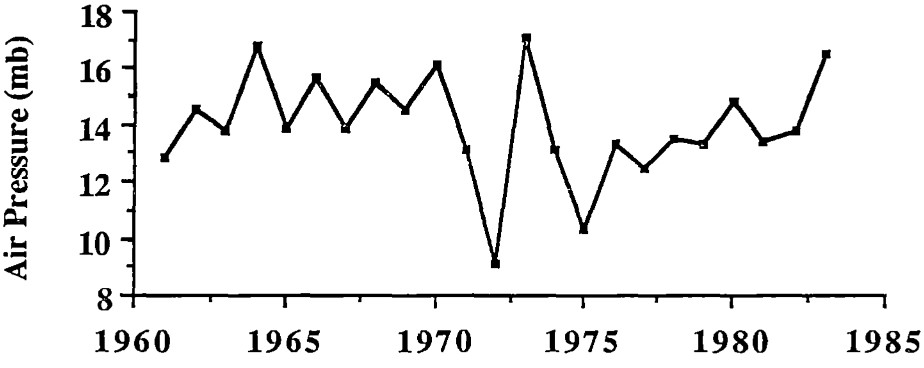


Figure 5.24
Number of Westerly Wind Days per Year (data from Harris et al. 1988)

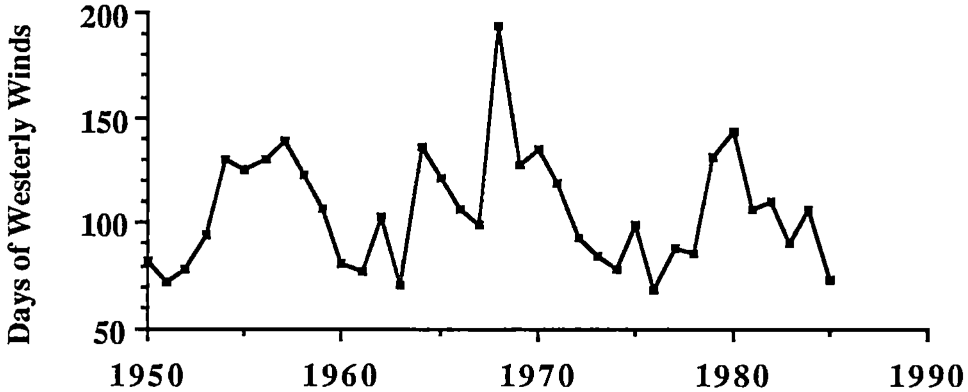


Figure 5.25
The Southern Oscillation Index (data from Harris et al. 1988)

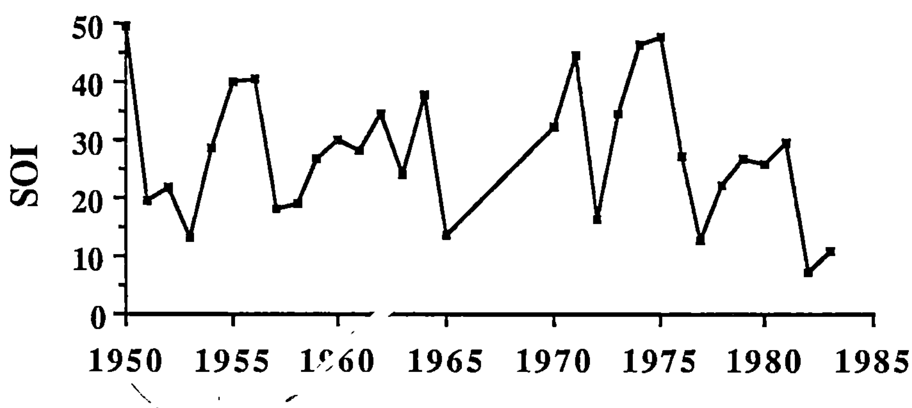


Figure 5.26
Maximum Sea Surface Temperature off Maria Island
(data from Harris et al. 1988)

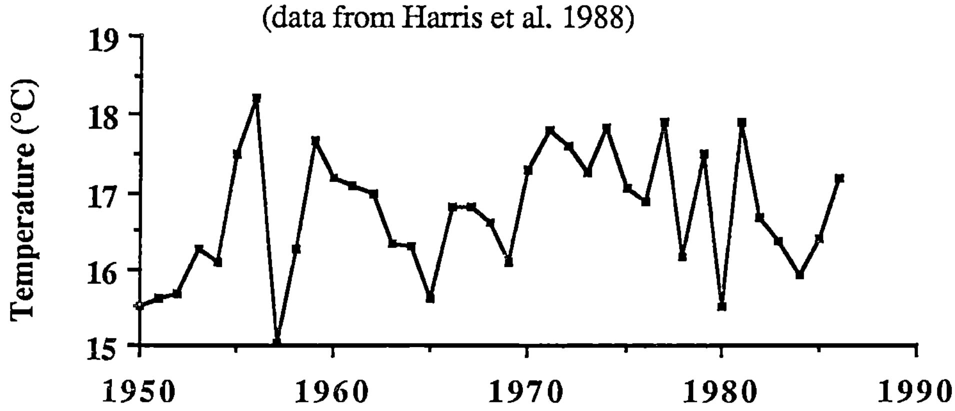


Figure 5.27

Timing of Spring Bloom off Maria Island
(data from Harris et al. 1988)

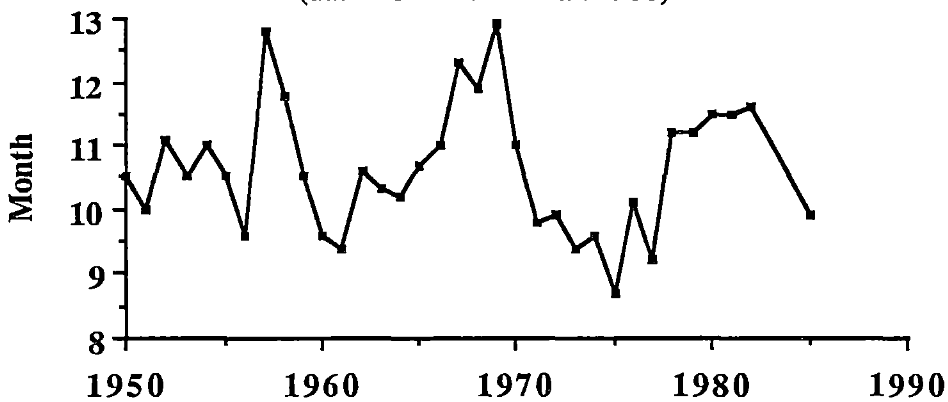


Figure 5.28

Number of Geomagnetically Disturbed Days per year
(data from Thompson 1985)

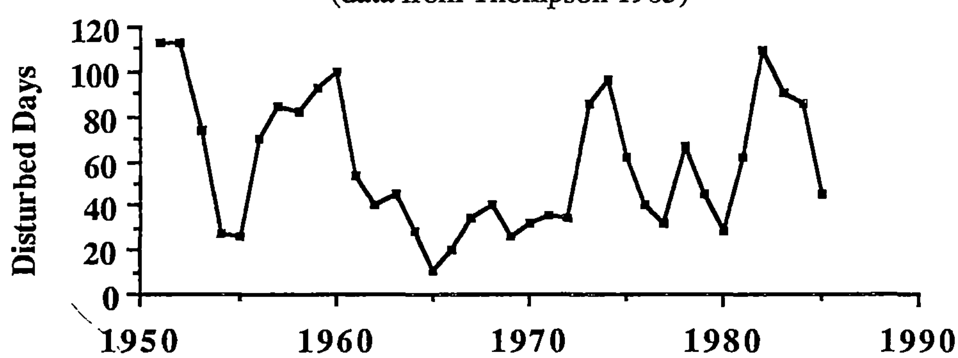
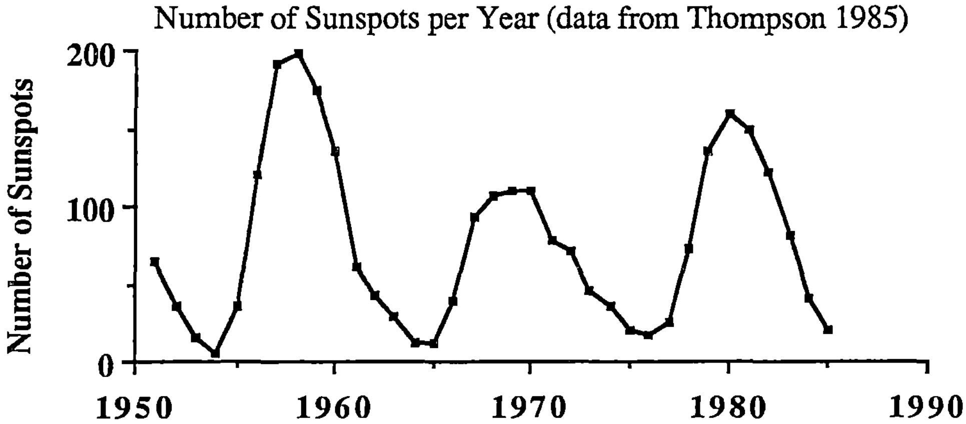


Figure 5.29

Number of Sunspots per Year (data from Thompson 1985)



vi) MAXIMUM SEA SURFACE TEMPERATURE OFF MARIA ISLAND (Max SST) (Fig. 5.26), the maximum annual sea surface temperature (°C) off Maria Island, reveals variations in the magnitude of the seasonal sea temperature cycle. It also indicates the relative position of the Sub-Tropical Convergence Zone (STCZ) off Maria Island and southeastern Tasmania. In years with low maximum SST the northern boundary of the STCZ will be off Maria Island (Harris *et al.* 1987). Sea temperatures appear to be increasing over the long term (Rochford 1975; Harris *et al.* 1987).

vii) TIMING OF SPRING BLOOM OFF MARIA ISLAND (Spring) (Fig. 5.27) is the period of rapid increase in planktonic biomass off Maria Island, which varies over four months centring around November (Rochford 1975; Harris *et al.* 1987).

5.3.2.3 GEOMAGNETIC DISTURBANCES

Two sets of data relating to geomagnetic disturbances, numbers of geomagnetically disturbed days per year (Fig. 5.28) and sunspot number (Fig. 5.29) were obtained from Thompson (1985). Geomagnetic disturbances, the result of solar activity, are very cyclic in nature. Thompson uses the global A index as the measure of geomagnetic disturbance, with 25 A_p the minimum level of disturbance required before a day was considered to be disturbed . Thompson gave no indication why different minimum levels where used for the seasonal (36 A_p) and annual data (25 A_p).

Sunspot numbers are the total number of sunspots and sunspot groups visible on the sun's surface each year, which is a measure of solar activity. Increases in sunspots leads to a rise in geomagnetic disturbances. The solar cycle has a second phase where the number of long-lived coronal holes on the surface of the sun increase while the number of sunspots decline. The coronal holes also increase geomagnetic disturbances (Thompson 1985).

5.3.2.4 STATISTICAL METHODS

The various environmental features where compared with each other for linear relationships using regressions analyses and tested for significances using the correlation coefficient (Snedecor and Cochran 1980). Then, the stranding databases where compared with the environmental features. The general null hypothesis was that variation in the dependent variable (the stranding data) could not be explained by the variations in the independent variable (the environmental features). The linear regressions and correlation coefficients were calculated using the graphics and statistical computer programme, "CRICKET GRAPH" (Raffarty and Norling 1986).

5.3.3 RESULTS

5.3.3.1 RELATIONSHIPS BETWEEN CLIMATOLOGICAL AND OCEANOGRAPHIC FEATURES

The marine environment is the result of interactions between an area's climate and oceanography (Beer 1983; Harris *et al.* 1987, 1988). These interactions and their influences on the Tasmanian marine environment are examined in Harris *et al.* (1987, 1988) and some of their findings have been included below. Table 5.1 shows the significant correlations obtained in this study. The comparisons involved various time lags ranging from minus one to plus one years. Figure 5.30 is a flow chart of how these features are interconnected, using correlations presented below and some from Harris *et al.* (1988). The thick lines connecting SOI with air pressure over Darwin, and the air pressure difference between Hobart and Macquarie Island with air pressures over Hobart and Macquarie Island indicate fixed causal relationships between these features since the former, in each case, is derived from the latter features. Negative and positive correlations are denoted by - and +, respectively. The time delays are shown by the relevant sign and number of years. Some lines have more than one correlation, all of which are recorded. The relationships involving zero time lags will be discussed first.

Westerly wind intensities are negatively correlated with air pressure over Hobart since when Tasmania is under the influence of a high pressure system the band of intense westerly winds has moved south. The band of westerly winds move north over Tasmania when the high pressure systems over central Australia move north . A similar correlation was obtained by Harris *et al.* (1988) between westerly winds and air pressure over Macquarie Island.

The timing of the planktonic bloom is positively correlated with the intensity of westerly winds because periods of frequent westerly winds will delay the onset of the bloom due to increased mixing. The mixing prevents the initial build up of planktonic biomass necessary for any rapid expansion of the biomass. The length of the planktonic bloom also is affected by westerly winds as years with frequent westerly winds tend to have long and more intense spring blooms

TABLE 5.1

Correlations between climatological and oceanographic features related to the Tasmanian marine environment. Statistical analyses performed by "CRICKET GRAPH" involving a series of time lags of between -1 and +1 years. Comparisons involved; AP Hobart with AP Macq Is, ZWW, SOI, Max SST and Spring, AP Macq Is with ZWW, SOI, Max SST and Spring, Diff AP with ZWW, SOI, Max SST and Spring, ZWW with Max. SST and Spring, SOI with ZWW, Max SST and Spring, and Max SST with Spring. Only statistically significant correlation coefficients (R) have been presented here.

INDEPENDENT VARIABLES	DEPENDENT VARIABLES	R	DF	SIGNIFICANCE	TIME LAG
AP Hobart	ZWW	-0.54	34	***	0
	SOI	+0.37	28	*	+1
	Spring	-0.37	31	*	-1
AP Macq Is	Max SST	+0.54	21	**	+1
Diff AP	SOI	-0.72	17	***	-1
ZWW	Spring	+0.52	32	**	0
		+0.54	30	*	+1
		+0.51	32	**	-1
SOI	Spring	-0.42	27	*	0
Max SST	Spring	-0.47	33	**	0

NOTES:

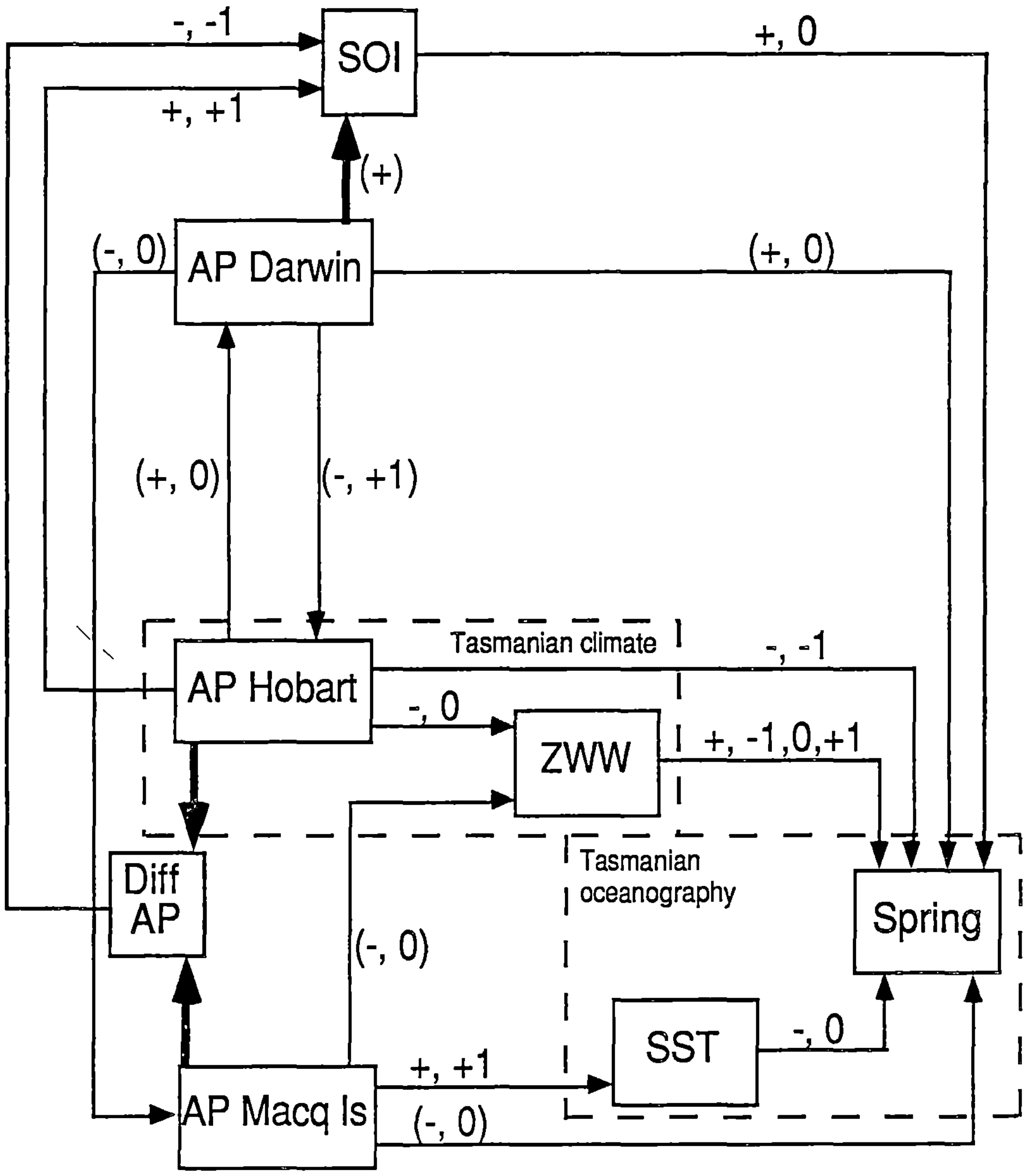
LEVELS OF STATISTICAL SIGNIFICANCE: * = P<0.05, ** = P<0.01 *** = P<0.001

ABBREVIATIONS USED IN TABLE:

AP Hobart = average annual air pressure over Hobart
AP Macq Is = average annual air pressure over Macquarie Island
Diff AP = differences in average annual air pressure between Hobart and Macquarie Island
ZWW = number of days with Zonal Westerly Winds
SOI = Southern Oscillation Index
Max SST = maximum sea surface temperature (°C) off Maria Island
Spring = month of plankton bloom off Maria Island.

FIGURE 5.30

The correlations between various climatological and oceanographic features, and components of the Tasmanian marine environment to indicate how the features are interconnected. Significant correlations are indicated by + = positive correlations, - = negative correlations, and time lags are indicated by 0 = zero years, +1 = positive one year, -1 = negative one year. Abbreviations are given in Table 5.1.



due to mixing after the initial spring bloom increasing nutrients in the upper layers of the water column (Harris *et al.* 1988).

Timing of spring blooms are negatively correlated with both maximum sea surface temperatures and SOI. In the former, low temperatures will slow down biological processes. Low SOI (warm ENSO) have been associated with sea temperatures and westerly winds, therefore, the latter correlation is a combination of low sea temperatures and increased mixing off Tasmania (Harris *et al.* 1988).

Three correlations involved negative one year time lags; planktonic blooms occurred earlier in years prior to a year of high Hobart air pressure and later in years prior to a year of high numbers of westerly winds, and SOI is low before a year with a large difference in air pressure between Hobart and Macquarie Island. The first two correlations are related to each other through the relationship of westerly winds to Hobart air pressure. The latter correlation operates through connections between air pressure over Hobart, Macquarie Island and Darwin.

Correlations with a positive time lag include SOI is low in the year after low Hobart pressure, maximum sea temperatures was high in the year after high Macquarie Island air pressure and the bloom in plankton was delayed after a year with a high frequency of westerly winds.

Overall, the level of primary production in the Tasmanian marine ecosystem is affected by most of the factors examined, as indicated by many of the pathways in Figure 5.30, directly or indirectly, leading to the timing of the spring bloom. The effect of the correlations between air pressure over Darwin and SOI with Spring Bloom are inconsistent with the remainder of the pathways within Figure 5.30. An important feature of the system is that the trio of air pressures (Darwin, Hobart and Macquarie Island) are all inter-connected and are likely to be major components in the initial development of ENSO events (Harris *et al.* 1988).

5.3.3.3 COMPARISONS BETWEEN STRANDINGS AND ENVIRONMENTAL FEATURES

The results of the comparisons between the Stranding indices and the various environmental features are given in Tables 5.2. Only significant correlations are presented. Of the ten stranding data bases only two species and two species combinations displayed significant correlations with the environmental factors and they will be presented below.

TABLE 5.2

Correlations of the Stranding Indices of various cetacean species and species groups, with aspects of the Tasmanian environment. Statistical analyses were performed by "CRICKET GRAPH" and involved a series of time lags of between -1 and +1 years. Only statistically significant correlation coefficients (R) have been presented here.

CETACEAN DATA	ENVIRONMENTAL FEATURE	R	DF	SIGNIFICANCE	TIME LAG
Long-finned Pilot Whales	SOI	0.37	28	*	0
Pygmy Right Whales	Max SST	0.35	33	*	0
Beaked Whales	Max SST	0.34	32	*	-1
Coastal Dolphins	ZWW	0.42	29	*	+1

NOTES:

LEVELS OF STATISTICAL SIGNIFICANCE:

* = Probability of between 0.05 and 0.01 of being correlated, therefore reject H_0

ABBREVIATIONS USED IN TABLE:

ZWW = number of days with Zonal Westerly Winds
SOI = Southern Oscillation Index
Max SST = maximum sea surface temperature (°C) at Maria Island

LONG-FINNED PILOT WHALES

The stranding index of long-finned pilot whales was positively correlated with SOI, without any time lag (Fig. 5.31). The correlation indicates that pilot whale strandings increased in years with high SOI, that is, years of cool ENSO events.

PYGMY RIGHT WHALES

Pygmy right whales strandings were positively correlated with maximum SST (Fig. 5.32), so that strandings increased in years with high SST.

BEAKED WHALES

The stranding index for beaked whales was negatively correlated with maximum SST (Fig. 5.33) with a negative time lag. The relationship indicates that beaked whale strandings increased around Tasmania during years prior to years with low SST off Maria Island.

COASTAL DOLPHINS

The combination of Coastal Dolphins was negatively correlated with the number of Zonal Westerly Winds with a positive time lag (Fig. 5.34). The combined strandings of common and bottle-nosed dolphins increased in years after a year of good weather (i.e. low ZWW).

5.3.4 DISCUSSION

Before discussing overall trends and implications of these results it is important to remember that significant correlations do not prove any causality between the variables. It is also helpful to describe how the various time lags work. Negative time lags arise where the frequency of strandings are compared with environmental features that occurred *after* the strandings. It may seem to make little sense to say that strandings are affected by events that occurred in the year after they did, however, the environmental features are continuous processes of which the data are yearly averages, totals or single points in the processes. The aspect of any feature that might be affecting strandings may not be that represented by the data. Positive time lags arise where the stranding frequencies are compared with features that occurred *prior* to the strandings. Again, this could be a reflection of the influence of another aspect of the feature. In addition, the effect of any feature may take time to show in the stranding record.

Figure 5.31

Comparison of the Stranding Index of Long-finned Pilot whales with the Southern Oscillation Index

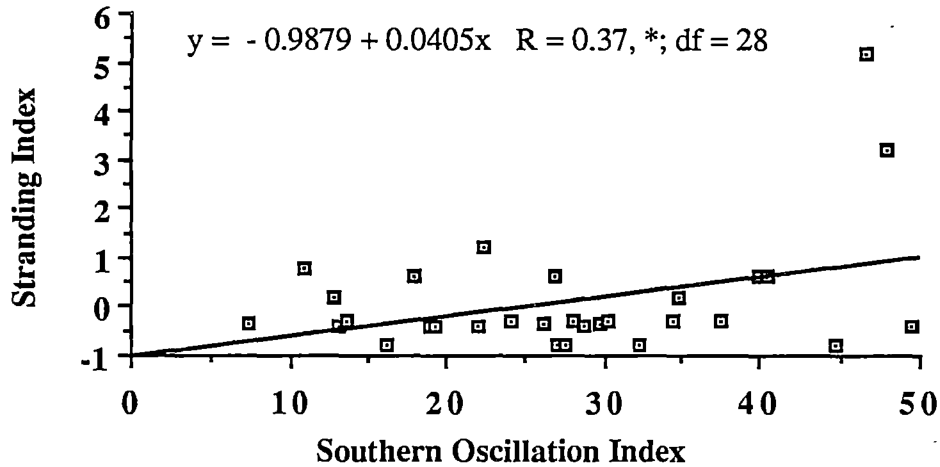


Figure 5.32

Comparison of the Stranding Index of Pygmy Right Whales with maximum Sea Surface Temperature

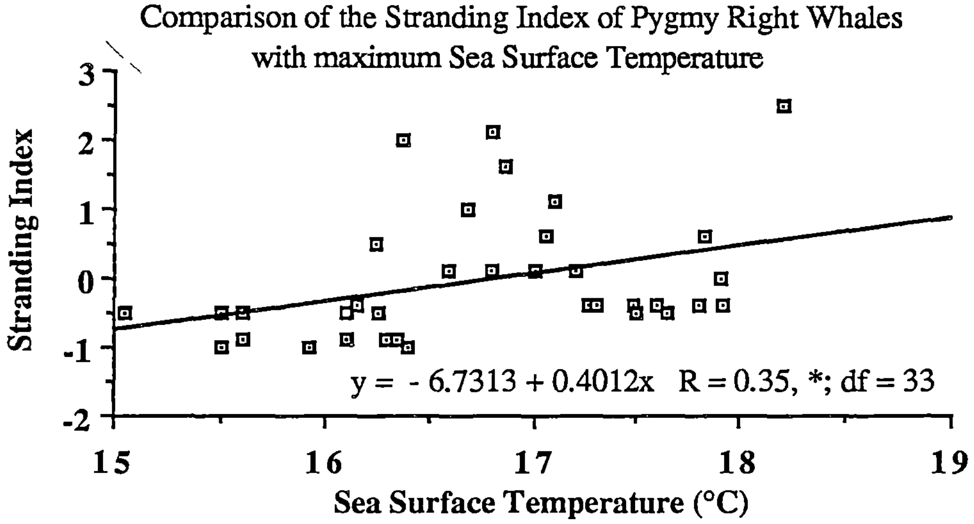


Figure 5.33

Comparison of the Stranding Index of Coastal Dolphins with Zonal Westerly Winds, on a +1 year time lag

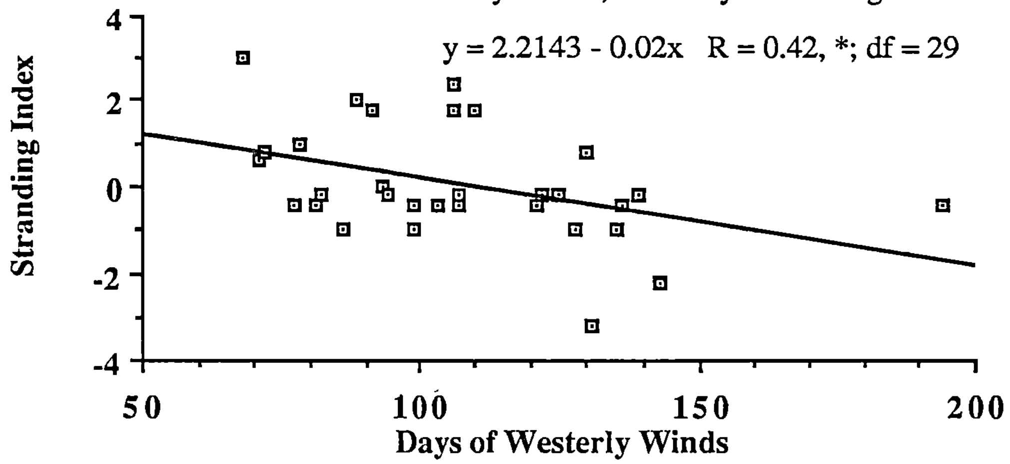
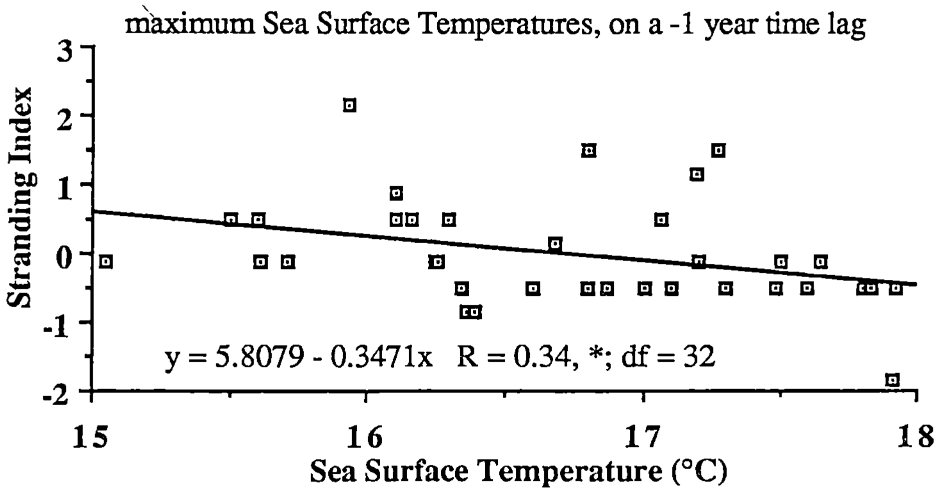


Figure 5.34

Comparison of the Stranding Index of Beaked Whales with maximum Sea Surface Temperatures, on a -1 year time lag



Time lags investigated ranged from minus one to plus one years, however, these lags were not used on all environmental features. Negative time lags were only used for SOI, Spring Bloom and maximum SST since these features are point measurements in continues processes. Positive time lags were used with all features except Geomagnetically Disturbed Days and Sunspots since any influence of these features should be immediately (i.e. hours or days), not after a year or so.

In total 210 linear regressions were calculated, being comprised of ten stranding data sets compared with three variables three times (minus, zero and plus time lags), five variables twice (zero and plus one time lags), plus 2 variables once (zero only). The four significant correlations represent only 2% of the calculations, and since all significant correlations were at the 0.05 level a real consideration has to be that they were only the result of chance. However, if this limitation is kept in mind, the significant correlations can be considered as indicative of factors worth cautious discussion and further examination.

The correlation of more frequent long-finned pilot whale strandings during years with high SOI, that is cool ENSO events, could have operated via the positive connection between SOI and air pressure over Hobart, whereby there are more frequent periods of settled weather occur during cool ENSO years. Thus, pilot whales may have been induced inshore by the settled weather. SOI is also connected to the timing of the spring bloom (as is Hobart air pressure) thus there is the possibility of changes in Tasmania's oceanography during cool ENSO years influencing pilot whales while they are in Tasmanian coastal waters, where their greater abundance might increase the potential influence of other factors.

The positive correlation between pygmy right whales and maximum sea temperature off Maria Island may indicate that these whales undertaking inshore movements during warm stable years. Several authors, in order to explain reported peaks in strandings over the summer have already suggested that pygmy right whales move inshore (Davies and Guiler 1957; Ross *et al.* 1975; Guiler 1979; Baker 1985). Baker (1985) reported that the distribution of strandings and sightings of pygmy right whales occur between the 5°C and 20°C isotherms. Therefore, considering that the upper temperatures off Maria Island are in the region of 17.5 to 18.5°C (Fig. 5.27), pygmy right whales may be stranding more frequently around Tasmania when the sea temperature approaches the upper end of the species' usual range. Increased stress due to the higher temperatures may be an important factor in the strandings of pygmy right whales.

A cautionary note needs to be sounded here in that several of this species' strandings occurred on the northwest corner of Tasmania, too far from Maria Island for variations in sea temperature off Maria Island to be a reliable indicator of the local conditions in the northwest.

Beaked whale strandings appear to be high during the year before low maximum sea temperatures. Variations in sea temperature are an indicator of the location of the northern boundary of the Sub-Tropical Convergence Zone (STCZ) (Harris *et al.* 1987, 1988) and are correlated with air pressure over Macquarie Island in the previous year. The distribution and abundance of beaked whales have been related to the location of the STCZ off New Zealand (Gaskin 1971), therefore the increase in strandings could be due to availability of beaked whales due to the higher productivity associated with convergence zones (Gaskin 1971, 1982; Beer 1982).

The distributions of beaked whales generally extend into the Southern Ocean south to the Antarctic Convergence Zone, with a few species being reported south of the Antarctic Convergence Zone (Gaskin 1982; Goodall and Galeazzi 1985; Evans 1987). Beaked whales have been reported from strandings on Macquarie Island (Copson, Tas. Parks, Wildlife and Heritage, personal communication). Therefore, since beaked whale strandings increased during years with low average air pressure over Macquarie Island the resulting poor weather around Macquarie Island may have affected the local food supply of beaked whales, eventually leading to more strandings around Tasmania. Harris *et al.* (1988) reported that fluctuations in the weather around Macquarie Island affected the sub-antarctic distributions of leopard seals.

The influence of westerly winds on the combined stranding records of Coastal Dolphins was that following stable years (low ZWW) strandings increased possibly because more dolphins had moved inshore, induced there by the good weather of the previous years. The greater availability of coastal dolphins during years that may not be stable would increase their susceptibility to factors, such as sudden storms or tidal entrapment.

Overall, there are indications, albeit weak ones, that some stranding frequencies are affected by the environmental features in the Tasmanian marine environment. The underlying factor in the four significant correlations appears to be the Darwin-Hobart-Macquarie Island pressure gradient which, in turn, affects westerly winds, a dominant feature of Tasmanian weather. Most factors influenced the productivity of the Tasmanian marine environment, as represented by Spring Bloom, which might indirectly affect cetacean strandings through changes in the abundance of prey, as has been suggested in other areas of the world (Sheldrick 1979, Whitehead and Carscadden 1985). Unfortunately, information about the diet of the Tasmanian cetacean fauna, the abundance and variability of the fish and squid populations off Tasmania are not available, thus further investigations are not yet possible.

An overriding consideration with these results has to be that the influences of observer effort were not been completely removed. For example, periods of fine stable weather would also have high levels of observer effort. In addition, lumping data into yearly averages or totals reduces the data's variability which might have been the important aspect of the factors. To over come these limitations the next step would be to examine the weather and oceanographic conditions at, and before, particular strandings, unfortunately, this level of detail is not currently available.

5.4 General Discussion

Prior to re-examining the studies' working hypothesis the major results obtained in the present Chapter will be summarised.

Seasonal Variation

1. The stranding records of several cetacean species showed significant seasonal variations, with most records peaking during the summer.

2. Only the seasonal strandings of long-finned pilot whales were significantly correlated with the seasonal variations in sea surface temperature.

3. There were no significant correlations with the seasonal variations in salinity and geomagnetic disturbances.

4. The influence of observer effort, itself probably seasonal, on the stranding records could not be completely removed and could still explain some of the variations in the stranding record.

Annual Variation

1. Stranding records for a few cetacean species were significantly correlated with fluctuations in various environmental features.

2. The environmental features included aspects of Tasmania's weather (Hobart air pressure and westerly winds), and oceanography (sea temperature), along with several features that affect Tasmania's environment at a distance (Macquarie Island air pressure) or were indicators of possible changes around Tasmania (SOI).

3. Again, the influence of observer effort may not have been completely removed.

The working hypothesis of this study predicts that if environmental features influence cetacean strandings then frequencies of strandings should correlate with fluctuations in the environmental features. As indicated by this summary, such correlations were significant for only a few cetacean species around Tasmania. While these results support the predictions of the working hypothesis, they are weak and the influence of other factors were not completely removed, so a very cautious interpretation should be taken.

It was not possible to determine how the features influenced strandings but several mechanisms can be suggested. Features that might affect the susceptibility of cetaceans included stormy weather which either disorientates or stresses the animals. Features that affect the productivity of Tasmania's marine ecosystems, such as disruption of the planktonic bloom by westerly winds or intrusions of different water masses, may also influence the susceptibility of cetaceans through their prey. Influences on the availability of cetaceans to strand, via their distributions, include changes in circulation patterns and locations of oceanographic features (such as water masses or convergence zones). Some features might influence both availability and susceptibility, such as unsettled weather affecting the physical well being of animals as well as the productivity of an area.

An important consideration to come out of the seasonal examinations was that the important factors might be unexpected events, such as unseasonable storms or magnetic disturbances during normally quiet periods, rather than regular and expected events. To investigate what aspects of the features might have been affecting the stranding rates data of greater detail are needed, particularly relating to environmental conditions at individual strandings. Another aspect is the comparison of the distribution and abundance of cetaceans around Tasmania with fluctuations in environmental features to see if the abundance of the cetaceans is a major factor in stranding rates.

CHAPTER 6 SUMMARY AND CONCLUSIONS

This study has established that the Tasmanian cetacean stranding record, to February 28 1986, contained 213 records involving 22 species and more than 3000 animals (Chapter 3). On the basis of the stranding records, along with occasional sighting reports, the Tasmanian cetacean fauna has been divided into common, frequent and rare visitors to Tasmania. The common visitors consist of seven species that stranded on more than 20 occasions and/or are regularly sighted. Frequent visitors include four species with between eight and 15 strandings. The remaining 11 species are rare visitors generally with a single event per species. The Tasmanian cetacean fauna belong to one of three zoogeographic affinities, Cosmopolitan (12 species), Austral Circumpolar (eight species) and Tropical (two species). The Cosmopolitan and Austral Circumpolar affinities each contained common, consistent or rare species, while, not unexpectedly, the Tropical affinity included only rare species.

Three main patterns emerged from the Tasmanian cetacean stranding record:-

1) The distribution of all cetacean strandings was clumped, which also was the case for most species;
2) Strandings reports peaked during the summer. Various patterns were shown by individual species including summer, winter or no discernible peaks; and,
3) The overall number of strandings reported each year has increased, particularly during the past 20 years.

Variations in the intensity and distribution of observer effort explained part of these patterns. A residual variation within each, however, indicates that cetacean strandings might have been influenced by other factors. Differences between the high numbers of strandings at both ends of the north coast contrasted with the low number of strandings in the central portion of the north coast could not be explained through variations in observer effort, thus some feature(s) of the physical environment must be either influencing the distribution of cetaceans or changing their susceptibility to strand. Two other areas with high numbers of stranding are the southeastern part of Tasmania and Ocean Beach on the west coast.

The peak period of all strandings was during the summer months, which also occurs with active and herd strandings, suggesting that strandings increased over this period. Greater observer effort explains the increase in the number of stranding reports per year, however, variations in annual stranding rates between years are due to some environmental factors affecting the availability and/or susceptibility of cetaceans to strand.

The study's working hypothesis proposed that some features of the physical environment could be influencing the distributions of cetacean strandings, therefore, to test these predictions aspects of oceanography, and coastal and geomagnetic topographies are compared with the distribution of active cetacean strandings around Tasmania (Chapter 4).

The major results of these examinations were:-

1) Strandings tended to occur in areas with complex oceanographic conditions;
2) Majority of active strandings occurred at sites with gently shelving topography and the proportions of strandings on shelving topography were significantly greater than the proportions of such topographies along the coasts; the non-significant result of the North Coast Region may indicate that steep coasts prevent strandings rather than shelving coasts cause them;
3) Active stranding sites tend to occur at, or near, local minima in the geomagnetic field but they were independent of the alignment of the contours of total field intensity.

Collectively, these results indicate that the distribution of cetacean strandings around Tasmania were influenced by aspects of the physical environment, in particular, combinations of oceanographic features, and coastal and geomagnetic topographical features. Oceanographic features possibly influenced cetacean strandings by two mechanisms, their abundance in and ability to cope with the nearshore area. The principal feature of coastal topography appeared to be the slope of the stranding site, with shelving beaches facilitating strandings while steep coasts may prevent them. In addition, the probability of strandings being discovered on shelving beaches is much greater than on steep coasts.

Geomagnetic topography influence the distribution of cetacean strandings because cetaceans appear to use aspects of the topography as an orientation aid. Cetacean strandings are not caused by errors in the use of this orientation aid immediately prior to a stranding, rather they stranded due to some other mistake and the geomagnetic topography is one of the determinants of the site of the stranding.

The working hypothesis also suggested that if environmental features were influencing the rate of cetacean strandings then seasonal and annual variations in stranding rates should correlate with fluctuations in the environmental features. To test these perditions, various climatic and oceanographic features, along with geomagnetic disturbances, were compared against the stranding records of some species (Chapter 5).

The results of the comparisons of seasonal variation were:-

1) Active, herd, common dolphin, sperm whale and long-finned pilot whale strandings peaked during the summer;
2) Long-finned pilot whale strandings were significantly correlated with the monthly average sea surface temperature; and
3) No stranding records correlated with monthly averages of salinity or geomagnetic disturbances.

Observer effort, itself seasonally affected, could explain some of the variations within the stranding data which might have contributed to the lack of significant results. In addition, clumping data into months reduced its variability and may have further prevented any significant correlations. Unexpected events, particularly during calm periods, could be important influences on strandings because they were not predicted, therefore, cetaceans can not prepare for the effects of such events.

The results of the examination of annual variation in stranding rates were:-

1) Strandings of two species and two species groups were significantly correlated, involving a range of time-lags, with various environmental features; and
2) The environmental features included components of Tasmanian climate (westerly winds) and oceanography (sea temperature and location of STCZ), distant indications of changes in the Tasmanian environment (SOI), and features affecting cetaceans during part of their migration cycle (weather around Macquarie Island).

Environmental features affected either the availability or susceptibility of cetaceans to strand via changing the distribution of cetaceans or altering their ability to cope with coastal conditions. Changes in the intensity or location of oceanographic features, such as convergence zones, may effect cetaceans via alterations in the productivity of the area. Frequency and intensity of rough weather can influence cetaceans via effecting an area's productivity or through associated heighten physically stress reducing the ability of the cetaceans to cope with the nearshore environment.

Overall, a major problem for the present study has been the lack of data about strandings (even basic data was not always reported) and their environmental features, limiting the scope of the investigation into the influence of these features on cetaceans. Again, unexpected events may have been important and clumping the data removed much of this variability. Examination of the particular environmental data for each stranding events is the next step. To provide more detailed data and to streamline its collection an integrated three tiered data collection procedure has been developed (Appendix III).

Now the working hypothesis can be re-examined and amended in light of the results presented above. In summary, the working hypothesis states that cetacean strandings are the result of errors in judgement made by cetaceans. Features of the physical environment influence the location and/or rates of strandings, by contributing to the condition that lead to the error of judgement. Aspects of cetacean behaviour, such as predator avoidance and social upheaval, also are contributing factors in the error.

The results of this study indicate that the distribution of cetacean strandings around Tasmania are influenced, if not caused, by the combinations of complex oceanographic conditions, and the location of gently shelving beaches near geomagnetic minima. The rate of strandings could have been influenced by fluctuations in the Tasmanian weather, marine environment and ecosystems, and changes in environments at some distance from Tasmania. The experience of the cetaceans involved with coastal conditions plus the health and behaviour of the cetaceans are likely to be major influences on whether a particular cetacean, or group of cetaceans, has difficulty and eventually strands.

Of the four main aims of this thesis outlined in the Introduction, three have been met, albeit partially. They are the establishment of the Tasmanian cetacean stranding record, identification of patterns within that record, and determination of the influence of environmental factors upon these patterns. The fourth aim of determining the causes of the strandings, however, has not been accomplished. This is, to a large extent, due to the very nature of the fourth aim. It is unlikely that a single cause or set of causes for all cetacean strandings can be identified because each stranding event is the result of a unique sequence of factors and circumstances, many of which are not discernible after the event. Thus, it was not possible to meet the overall objectives of this research project, to determine the causes of cetacean strandings around Tasmania and, therefore, to develop ways of preventing them. The study has identified some environmental factors that influence the distribution and/or rate of cetacean strandings and it may be possible, with further research into the connection between these factors and strandings, to develop a predictive model that could identify periods with heightened probability of strandings occurring. By monitoring appropriate environmental features warnings could be provided to the authorities and other interested parties of the approach of such periods. Until predictive models are be developed the authorities will have to continue to maintain a general state of readiness.

To investigate the mechanisms of how environmental features affected cetacean strandings more data of greater detail about individual events are required (see Appendix III). Over the next 10 or more years the maximum possible amount of details about strandings around Tasmania should be collected. Alternatively, a larger data base could be found. One option would be to use the cetacean strandings from around Australia, however, the size of the area and the number of bio-geographical zones involved might introduce as much, if not more, variation as arise from the various environmental factors. Another option could be to use the extensive stranding record in New Zealand (Baker 1981b, 1983; Dawson 1985) where the size of the country would not introduce the same degree of variation as in Australia.

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APPENDIX I: GLOSSARY OF CETACEAN SPECIES MENTIONED IN THE TEXT

PART 1 - SPECIES CONFIRMED AS OCCURRING AROUND TASMANIA

SCIENTIFIC NAME **Suborder**			COMMON NAME
	Family	**Species**	
Mysticeti			Baleen whales
	Balaenidae		Right whales
		Eubalaena australis Desmoulins, 1822	Southern right whale
		Caperea marginata (Gray, 1846)	Pygmy right whale
	Balaenopteridae		Rorqual whales
		Balaenoptera acutorostrata Lacépède, 1804	Minke whale
		B. borealis Lesson, 1828	Sei whale
		B. musculus (Linnaeus, 1758)	Blue whale
		B. physalus (Linnaeus, 1758)	Fin whale
		Megaptera novaeangliae (Borowski, 1781)	Humpback whale
Odontoceti			Toothed whales
	Ziphiidae		Beaked whales
		Berardius arnouxi Duvernoy, 1851	Arnoux's beaked whale
		Hyperoodon planifrons Flower, 1882	Southern bottlenosed whale
		Ziphius cavirostris G. Cuvier, 1823	Cuvier's beaked whale
		Mesoplodon densirostris (de Blainville,1817)	Densebeaked whale
		M. grayi von Haast, 1876	Gray's beaked whale
		M. hectori (Gray, 1871)	Hector's beaked whale
		M. layardi (Gray, 1865)	Strap-toothed whale
	Physeteridae		Sperm whales
		Physeter macrocephalus Linnaeus, 1758	Sperm whale
	Delphinidae		Dolphins
		Delphinus delphis Linnaeus, 1758	Common dolphin

Lissodelphis peronii (Lacépède, 1804)	Southern right whale dolphin
Tursiops truncatus (Montagu, 1821)	Bottle-nosed dolphin
Globicephala melaena (Traill, 1809)	Long-finned pilot whale
G. macrorhynchus Gray, 1846	Short-finned pilot whale
Orcinus orca (Linnaeus, 1758)	Killer whale
Pseudorca crassidens (Owen, 1846)	False killer whale

PART 2 - SPECIES NOT IDENTIFIED FROM TASMANIAN WATERS

SCIENTIFIC NAME Suborder Family	Species	COMMON NAME
Mysticeti		Baleen whales
Balaenopteridae		Rorqual whales
	Balaenoptera edeni Anderson, 1878	Bryde's whale
Eschrichtiidae		Gray whales
	Eschrichtius robustus (Lilljeborg, 1861)	Gray whale
Odontoceti		Toothed whales
Ziphiidae		Beaked whales
	Tasmacetus shepherdi Oliver, 1937	Tasman beaked whale
	Mesoplodon bidens (Sowerby, 1804)	Sowerby's beaked whale
	M. bowdoini Andrews, 1908	Andrews' beaked whale
	M. mirus True, 1913	True's beaked whale
	M. stejnegeri True, 1885	Stejneger's beaked whale
Physeteridae		Sperm whales
	Kogia breviceps (de Blainville, 1838)	Pygmy sperm whale
	K. simus Owen, 1866	Dwarf sperm whale
Monodontidae		Arctic whales
	Delphinapterus leucas (Pallas, 1776)	Beluga
Delphinidae		Dolphins

	Lagenorhynchus cruciger (Quoy and Gaimard, 1824)	Hourglass dolphin
	L. obscurus (Gray, 1828)	Dusky dolphin
	Cephalorhynchus heavisidii (Gray, 1828)	Heaviside's dolphin
	C. hectori (van Beneden, 1881)	Hector's dolphin
	C. commersoni (Lacépède, 1804)	Commerson's dolphin
	Stenella spp	Spinner and Spotted dolphins
	Feresa attenuata Gray, 1874	Pygmy killer whale
	Grampus griseus (G. Cuvier, 1812)	Risso's dolphin
Phocoenidae		Porpoises
	Australophocoena dioptica (Lahille), 1912	Spectacled porpoise
	Phocoenides dalli (True, 1885)	Dall's Porpoise

APPENDIX II: TWO IMPORTANT CETACEAN STRANDINGS AROUND TASMANIA DURING 1989

During 1989 two important strandings occurred around Tasmania.

1. A live false killer whale was discovered in a beach in southeastern Tasmania (Anderson 1991). The animal was returned to the sea and eventually swam off. No further sightings were made of the animal. This is the first stranding involving a false killer whale around Tasmania since 1976.

2. A dead pygmy sperm whale was discovered on an exposed beach along the south coast of Tasmania (Anderson 1991), and the skull was collected. The discovery of this whale is the first confirmed report of this species stranding around Tasmania, although an undocumented skull held by the Tasmanian Museum and Art Gallery that had been previously attributed to Tasmania (Section 3.2.2). With the addition of this species there are now 23 species confirmed as having been reported from Tasmania.

APPENDIX III DATA COLLECTION FROM CETACEAN STRANDINGS

INTRODUCTION

A major problem encountered during this study was the lack of sufficient data of suitable quality. Many of the basic details about strandings were not always published. Whether or not animals were alive at the time of stranding was not always reported, therefore, their health status could not be determined. In addition, the date of stranding was not consistently provided reducing the data for examinations of temporal variations. The lack of exact location for some strandings reduced the data available for analysis of the distribution of strandings. The use of a standard data collection procedure would have maximised the amount of data collected from the greatest number of strandings. A standard procedure would have to handle a range of species, sizes and numbers of animals, and states of decomposition, while incorporating the needs of organisations rescuing animals and researchers collecting biological data.

The value of information from cetacean strandings has been recognized for many years and attempts have been made to standardize the collection (Norris 1961; Baker 1972, 1981b, 1983; Fraser 1976; Geraci and St Aubin 1979a; Watson 1981; Warneke 1986). The first attempts concentrated on describing the animals and their biology, with data consisted mainly of external measurements, descriptions of external appearance and autopsy details. The major aims of these procedures were to establish species identity, taxonomic relationships, distributions of populations and species, and basic biology, such as reproduction and diet. Another group of data that can be collected describe the stranding events, covering the physical environment of the stranding site, and behaviour of the animals. The two principal aims behind the collection of such data are the study of patterns and causes of cetacean strandings, and to assist with the organisation of rescue operations.

It is not always possible to collect all available data due to restrictions in time and/or personnel. In such situations, and when the expertise of the collector(s) are not very great, it would be very helpful to know which of the multitude of data items awaiting collection should, and can, be recorded first. Guidance could be provided if each data item was ranked according to its importance and level of accuracy required (International Whaling Commission 1986). Such a procedure would represent a significant improvement over the previous procedures. The aim of this Appendix is to outline a collection procedure that uses a three-tiered system to meet the different needs and demands of the various user groups. Before introducing the procedure, there will be short reviews of the potential data available from cetacean strandings and the existing data collection procedures.

DATA AVAILABLE AT CETACEAN STRANDINGS

Data available from cetacean strandings can be divided into two groups; (1) the animals and their biology, and (2) the stranding event. Any list of data items can not be exhaustive because new areas of investigation arise as our knowledge of cetaceans, and their strandings expands. This section examines the data current considered to be available from strandings and limitations imposed on data collection by constraints in time personnel and the stage of decomposition of the animals. The major sources of information in this section are Norris (1961), Baker (1972, 1981a, 1981b, 1981d, 1983), Fraser (1976), Geraci and St Aubin (1979a), International Whaling Commission (1986), and Warneke (1986). Specific references will be mentioned where relevant.

DATA CONCERNING THE ANIMALS

Information that can be collected from animals at a stranding site can be categorised into external appearance, stranding behaviour and internal structure. A short explanation will accompany the data items in each category. The order of items in the lists do not imply any ranking of importance.

EXTERNAL APPEARANCE

1. *General*; includes number of animals plus their general condition, that is, alive, dead, or decomposed.
2. *Colour Patterns*; important for identification at both the individual and species levels. Colour patterns on dorsal, lateral and ventral surfaces plus unusual features are the important aspects.
3. *Appendages;* descriptions of dorsal and pectoral fins (flippers), and tail flukes (including tail notch) are useful in determining species, sex and relative age of some animals.
4. *Head Region*; used for species identification and determining relative age, including descriptions of teeth or baleen, throat grooves, beak and/or melon, and blowholes.
5. *Genital Region*; principally to ascertain sex and reproductive condition. It is not easy to sex cetaceans as the external openings of both sexes are very similar.

6. *Unusual Features*; including scars, fresh or partly healed wounds and other markings, all help identify individuals during, and subsequent to, a stranding.
7. *External Parasites*; many parasites are species and region specific, thus they can be used to determine an animal's recent long range movements, and they also indicate the animal's general health condition.

Early data collection procedures usually requested sketches of animals which depend on the skill of the observer. Recently, authors have requested that photographs be taken. A good set of photographs can assist with determining species identity, size and sex.

STRANDING BEHAVIOUR

Strandings, in particular the pre-stranding period, provide rare opportunities to observe cetacean behaviours, albeit in unusual circumstances. Descriptions of these behaviours may provide clues about conditions that contribute to, or cause, strandings, therefore any cetacean behaviour should be recorded during the stranding, notably; pre-stranding, act of stranding, while ashore and throughout any rescue operations. Several general categories of behaviour can occur, including vocalizations, various swimming patterns, "care-giving" and "leadership activities".

It is important to be able to identify individuals. Both natural markings, and artificial tags and markings have been used in the past. The principal natural markings are colour patterns, position, shape and number of scars, and unusual features (such as missing or misshapen dorsal fins, flippers or tail flukes). Artificial tags include ribbons, button tags, cattle ear tags, vinyl spaghetti tags and various radio tags. Another artificial tagging method involves freeze-branding, providing a longterm, if not permanent, tag. The latter five types of tags involve piercing the skin in some way which raises ethical questions relating to the use of such invasive methods. Hobbs (1982) gives a summary of tagging methods.

INTERNAL EXAMINATION

There are several reasons for conducting internal examinations including determining health condition and reproductive status, identifying possible cause(s) of death, dietary studies, and collecting details of the general biology of cetaceans. The maximum amount of information is available from fresh specimens examined in laboratory conditions by experienced cetologists or veterinarians. Useful information, however, can still be collected in the field by people with some biological training.

The items are presented in the order that they are usually encountered during an examination.

1. *General*; all organs should be described, measured, weighed, and examined for parasites or unusual features. Samples should be kept of any unusual features, such as growths or injuries.
2. *Blubber*; the thickness and colour are indicative of the animal's condition. If the blubber is not creamy-white this may indicate a metabolic problem, for example, reduced kidney function.
3. *Muscles*; basically limited to signs of parasitic infection or wounds as details of fine anatomy, biochemistry or pathology require a high level of expertise under laboratory conditions.
4. *Reproductive Organs*; determine sex and reproductive status, including, for females, whether they are, or have been, pregnant and details of any foetus.
5. *Urinary Systems*; little information is available except under laboratory conditions except for checked for parasites.
6. *Digestive System*; the main interests are dietary information, including identification and relative importance of prey species, and presence of parasites. All contents should be collected.
7. *Respiratory System*; parasitic infections, other ailments or the presences of water in the respiratory tract are the main interests. The colour of the lungs may indicate health problems.
8. *Circulatory System*; the heart and major blood vessels can be checked for parasites or signs of damage.
9. *Nervous System*; the presence of parasites, primarily in the brain, are the main feature of interest. Any further examination requires laboratory conditions.
10. *Skeleton*; the bones, particularly the skull, are important in species identification and may also be useful in sexing and aging animals.
11. *Tissue Samples*; there are four main reasons for collecting tissues samples, examination of micro and cellular structures, pathology, levels of pollutants, and genetic studies.

DATA CONCERNING EVENTS

This section deals with the conditions that may have caused the stranding. The information is also of interest to those involved with rescue operations and can be divided into three groups: general aspects, topography and environmental conditions.

GENERAL

1. *Date and Time*; depending on when a stranding is discovered there are up to three dates and times, when the animals came ashore, when discovered, and when examined or rescued. The more accurate this information is the more useful the rest of the data will be.
2. *Location*; is important for relocation for rescue operations or scientific examinations, also important for investigations into patterns and causes of strandings.

TOPOGRAPHY

1. *Geographical Topography*; describes the physical structure of stranding sites, both on- and offshore, including nature and slope of substrate.
2. *Geomagnetic Topography*; covers two aspects of the earth's magnetic field, total field intensity and general alignment of contours at the site.

ENVIRONMENTAL CONDITIONS

1. *Weather Conditions*; general descriptions of the weather covering rainfall, temperature range, cloud cover, and wind direction and strength.
2. *Sea Condition*; including sea state, size and direction of swell, and water temperature.
3. *Tidal Phase*; the state of the diurnal and monthly tidal cycles.
4. *Moon Phase*; related to monthly tide cycles, however, they are not synchronised thus they need to be recorded separately.
5. *Geomagnetic Disturbances*; the occurrence and intensity of disruptions to the earth's magnetic field in the days preceding a stranding should be recorded.

Many environmental conditions cannot be determined if the date, and sometimes the time, of the stranding are unknown. Also, some data require equipment not always available at stranding sites, particularly details of the weather, tidal phase and geomagnetic disturbances, therefore these items need to be obtained from the appropriate authorities.

LIMITATIONS IMPOSED ON DATA COLLECTION

Shortages of time, equipment and/or personnel plus the state of decomposition of the carcass impose limitations upon data collection at strandings. Time can be reduced by the necessity of working between tides, fitting in with rescue operations or the share number of animals at large herd strandings can overload resources (Norris 1961; Geraci and St Aubin 1979a; International Whaling Commission 1986). At herd strandings, pressure arises from the conflict between the desire to collect all the data from some animals or some data from all the animals. The latter approach has often been followed to enable the details of sex, age and social structure of as large a group as possible should be collected (Guiler 1978; Geraci and St Aubin 1979a; Anderson 1982; McManus *et al.* 1984; Warneke 1986). The lack of trained personnel also reduces the data by excluding items requiring expertise and slowing the collection process, exacerbating the effect of any time limitations. Lack of trained personnel can also leads to the accuracy of the data being questioned.

Deterioration in the condition of the carcass dramatically decreases the information available. If decay is very advanced even external information is reduced. An extreme example is where the flesh has decomposed and the skeleton is disarticulated, then it is not possible to collect any biological data besides species. While expert cetologists and wildlife researchers may examine putrid carcasses it is unlikely that members of the public would collect even the most basic data from such a carcass, let alone large numbers of items as often requested. The collection of the skull and/or some teeth from putrid carcasses can still provide information on species, sex and age, for some species.

Delays can occur between the discovery and the examination of a stranding. Factors contributing to such delays include public awareness of the importance of reporting strandings, availability of personnel and funds to attend the stranding. Locations that are remote and/or difficulty to get to cause delays, which can not always be eliminated.

THE PRESENT SITUATION

DATA FROM THE ANIMALS

Early scientific interests in cetacean strandings centred on identifying the species involved, thus they concentrated on morphometric information. The inclusion of information concerning additional aspects of a stranding in these early publications very much depended on what each researcher considered important. With morphometric information, there was little agreement over what data should be collected and what method should be used. Two alternative methods are available for collecting external measurements. One method measures directly over the animal's surface, while the other method involves "straight-line" measurements, that is the distance along a straight line parallel with the animal or the body part. The former method is subject to variable errors as body shapes changes due to differences in an animal's position and/or the effects of bloating, while the second method is less susceptible to these errors (Norris 1961; Baker 1972; Fraser 1976; Geraci and St. Aubin 1979a).

The first published attempt to standardize data collection was undertaken by Fraser (1976; originally published in 1949) as part of the cetacean stranding notification program at the British Museum (Natural History). The primary aim of this program was to maximize the number of stranding events reported, therefore, the data format was principally to establish species identity. Only six external measurements and a general description of the animal were requested.

The second attempt was made by the Committee on Marine Mammals of the American Society of Mammalogists (Norris 1961), who produced an extensive list of data items covering more than 40 external measurements, 10 questions on external appearance and questions on seven aspects of the stranding event. The procedure also requested life history data involving 25 questions on parasites, stomach contents and reproduction. The principal intention behind this data collection procedure was to standardize the data collected from small toothed and baleen whales, thereby enabling comparisons between events and researchers (Norris 1961). The standardised procedure also assisted researchers who have limited, or no, experience of strandings. The 48 external measurements were requested as they were the measurements that taxonomists considered necessary, especially for the separation of stocks. Some measurements are useful indicators of sex or age.

Norris (1961) acknowledged that time and personnel are often limiting factors at strandings and to assist, items considered to be the most important were identified. A total of 31 items were identified; still representing a substantial work load. At least, it was an attempt to rank items in order of priority for collection.

This standard data collection procedure has formed the basis of most of the subsequent stranding reporting forms, particularly those that concentrated on the animals (Leatherwood *et* *al.* 1976; Baker 1981b; Watson 1981; Leatherwood *et al.* 1982; Warneke 1986), with the number of items varying from 34 to 55.

Another group of authors have used the format originally proposed by Fraser (1976), with about 12 external measurements, together with comments on the stranding, and descriptions of behaviour (Baker 1972, 1983; Orr 1984; Dawson 1985; Kaufman and Forestell 1986). These authors were writing for the general public, unlike the authors mentioned previously who were predominantly aiming their requests at trained observers such as cetologists, field zoologist and wildlife officers, however, it is not possible to say whether variations in target audiences alone are sufficient to explain the differences in the number of measurements being requested or whether differences in the principal aims of the procedures are a factor.

In summary, there appears to be two schools of thought on what data should be collected from stranded cetaceans. One school, represented by Fraser (1976), requests only a few external measurements and a general description of the animal and is primarily aimed at maximising the number of events recorded. The other school, represented by Norris (1961), requests an extensive list of external measurements plus life history details so as to maximise the information collected about the animals involved. Variations between the two schools may reflect differences in their target audiences, the general public and the scientific community, respectively.

DATA ABOUT THE EVENT

Over recent years the number of attempts to rescue stranded cetaceans have increased and in such situations, rapid notification of, and responses to, a stranding enhances the prospects of success (Anderson 1982, 1985; McManus *et al.* 1984; Robson 1984; Dawson 1985; Whiteside 1985, 1987). Interest in investigating the causes of cetacean strandings has also been revived. Both factors have tended to shift the emphasis of data collection towards the inclusion of descriptions of behaviour and the physical environment (Baker 1972, 1981a, 1981b, 1983; International Whaling Commission 1986).

Information about the whales involved is still useful, such as species, size, condition and number of animals, and stage of the stranding (i.e. pre-stranding, in progress, recently stranded, freshly dead). Some earlier data collection procedures included questions on the physical environment and behaviour. For example, Norris (1961) had questions on general aspects of the event, however, the main emphasis was on the collection of quantifiable data about the whales.

Early descriptions of stranding events occasionally included details of behaviour and the physical environment, however, the actual details recorded often depended on what each author considered necessary or interesting. Overall, there has been no consistency in the information presented. Several factors contributed to this inconsistency, particularly the lack of an agreed standard list of questions. As well, the number of factors suspected of contributing to strandings has expanded resulting in greater numbers of data items being collected, two examples are the recent inclusion of details about the geographical and geomagnetic topographies of the stranding site. Geraci and St Aubin (1979a) and International Whaling Commission (1986) did provide lists of topography and environmental conditions that should be recorded, however, neither considered their lists to be comprehensive.

There are several positive points regarding the collection of environmental data; some features can be collected at any time after the event, the amount of information collected at herd and single strandings is the same, and many features do not require a high degree of training for accurate collection.

In summary, many authors have recognized that descriptions of the physical environment and cetacean behaviour are important, and should be recorded. No attempt has been made to provide a standard list of questions, due, in part, to the increasing number of factors that have been considered as possible causes of strandings, thereby, expanding the number of data items that could be collected.

NEW DATA COLLECTION PROCEDURE

Most data collection procedures acknowledge that it is not always possible to collect all the data request from some, let alone all, strandings (Norris 1961; Fraser 1976; International Whaling Commission 1986). In a review of data available from stranded cetaceans it was suggested that each data item should be ranked into one of three groups, thereby, assigning the items with their relative order of collection (International Whaling Commission 1986). The three main criteria for ranking an item were their relative importance, the amount of detail necessary and the required level of skill. On this basis, it is possible to develop a three-tier data collection procedure where each subsequent level involves greater complexity and requires higher levels of expertise for its collection. The three tiers of the procedure are also aligned with the three principal reasons for collecting information from stranded cetaceans, organisation of rescue operations , and interest in the animals and the event.

The new data collection procedure aim to have an integrated system enabling more information to be collected, even by non-experts. The procedure also operates within the constraints imposed by rescue operations. The lists of questions act as prompts and guides for the collection the data. The procedure's three stages have their own self contained data sheets, consisting of questions, both multiple choice or open ended. The first data sheet records the basic information about a stranding from the initial observer. Such information is needed to make the preliminary decisions about whether a rescue or data recovery operation should commence. The second data sheet records details of the stranding event, including the topography, environmental conditions, as well as aspects of the animals which are useful for investigations into causes of strandings. The third data sheet concentrates on biological information about the animals, from external and internal examinations. Each data sheet will be described, detailing the aims and necessary skills involved. Finally, the three data collection sheets are integrated into the new procedure.

DISCOVERY OF EVENT

As the chances of a successful rescue operation increase with the quick arrival of personnel and equipment at the stranding, the quality and quantity of the initial information is vital. The agency dealing with stranded cetaceans needs details about the event which describe the stage of the stranding, number, size and condition of the animals, access to, and exact location of the site, and a summary of the environmental conditions. **Data Sheet I** aims to record such information. This information is the basis of the initial decisions about whether or not a rescue operation is needed and, if so, of what size. **Data Sheet I** also records the basic data about any strandings in case the event can not be investigated further.

Data Sheet I consists of 12 categories of questions. The level of detail required for each item varies. It is, however, advantageous to always collect the highest level of detail possible.

Stage of stranding records how far the stranding has progressed, with each stage representing an important division in the continuous stranding process. The stages assist the authorities determine the urgency of the situation. Intervention at an early stage may prevent a stranding from proceeding further.

CETACEAN STRANDING DATA SHEET I
BASIC DATA

Either fill in blanks or circle appropriate answer. More than one answer may be appropriate.

1. **Stage of Stranding** - prestranding (all animals offshore)
   - in progress (some animals ashore)
   - recent (all animals ashore and alive)
   - established (some animals dead)
   - old (all animals dead)
   - bones
2. **Number of Animals** - alive ________
   (accurate figures if possible) - dead ________
   - unsure ________
3. **Size of Animals** (accurate figures, please) - largest animal ________
   - average animal ________
4. **Species** - ______________________________ (tentative)
5. **Photographs** - available YES / NO
   name and phone number: ______________________________
6. **Exact Location** (including any landmarks and map references)
   ____
7. **Access** - car, 4 wheel drive, boat, walking only, locked gates, private land
8. **Weather Conditions** - general: hot, sunny, cloudy, drizzling, raining, stormy
   - wind: direction - onshore, offshore, variable
   strength - nil, light, mid, strong
9. **Sea Condition** - calm sea, slight sea, rough sea, very rough sea
10. **Date and Time** - stranding date: ________ time: ________
    - discovery date: ________ time: ________
    - report date: ________ time: ________
11. **Name and Address of Initial Observer** - name: ________________
    address: ______________________________
    ______________________________ phone: ________
12. **Recording Officer** - ______________________________
    contact telephone - ________________ sign: ________________

Categories *Number of Animals* and *Size of Animals* indicate the extent of the problem facing rescuers. The larger the number, or size, of the animals involved the greater the difficulties in returning them to the sea and the more resources required. The number of cetaceans alive or dead provides a general impression of their condition when discovered.

Species identity can provide useful information, such as indicating the animal's likely size range, and acts as a check on some of the other information. Any identification, however, needs to be treated with a great deal of caution unless the species involved is easily identifiable or the observer has experience with cetaceans. *Photographs* can confirm and/or provide further details especially if, the event is not re-examined.

Exact location of a stranding is very important as faulty or misleading information about the location can result in delays, even failure, of rescue operations. The position should be fixed with map references and/or in relation to known landmarks *Access* indicates the type and/or difficulty of approaches to the stranding site.

Descriptions of the environmental conditions at stranding sites, both on land and at sea, are important because these conditions determine how long stranded cetaceans can remain ashore and still have a chance of being successfully returned to the sea. They also indicate the conditions under which a rescue operation would have to operate. Differences between when an event was discovered and reported are important indications of the valid of some of the information. The longer the difference the less valid some information becomes. The last two categories are to enable the information to be checked, if necessary.

EXAMINATION OF STRANDING EVENT

Following notification of an event, the next stage in the data collection is to describe the stranding event, including the physical and environmental conditions, behaviour and basic biological information. This information is useful for investigations into patterns, and possible causes, of cetacean strandings. **Data Sheet II** records such information while re-examining and expanding on the information in Sheet I.

CETACEAN STRANDING DATA SHEET II
STRANDING EVENT DATA

INTRODUCTION

At stranding involving live cetaceans the first priority is to return as many animals as possible to the sea. Data collection is secondary and must fit within rescue operations.
Either fill in blanks or circle appropriate answer. Note more than one answer may be appropriate. See diagram for details of sexing (8 ii) and measuring (8 iv) cetaceans.

1. Exact Location: - ____

____

2. Stranding Site:

i. Onshore
- slope - gentle, steep
- substrate - sand, pebbles, rocks, rock platforms
- topography - estuary, tidal flats, enclosed bay, semi-exposed, exposed beach, headland, island, isthmus
- orientation[1] - N, NE, E, SE, S, SW, W, NW

ii. Offshore - shoals, reefs, deep water, islands, open sea

Note 1 - "orientation" of a stranding site is direction when facing seaward and perpendicular to site's general alignment

3. Weather Conditions:

i General — hot, sunny, cloudy, drizzling, raining, stormy

ii Details[2]
- temperature (°C): min. __________ max. ____________
- cloud cover (%): __________ (estimate)
- wind: direction __________ strength (m/s) ____________
- rainfall (mm): __________

Note 2 - It may be necessary to contact the Bureau of Meteorology for these details, if so, state location of recording station and distance;

____

4. Sea Condition:

i General — calm sea, slight sea, moderate seas, rough sea, very rough sea

Beaufort Scale (0-2), (3-4), (5), (6) (>7)

ii Swell direction ________________ height __________________

iii Sea surface temperature (°C) __________

5. **Tidal Phase:**

i Daily cycle high, falling, low, rising

time of high water __________ height (m) ________

ii Monthly cycle date of spring tide __________ range (m) ________

date of neap tide __________ range (m) ________

6. **Moon Phase:**

nearest quarter of moon - full, last quarter, new, first quarter

date - _______________

7. **Geomagnetic Data[3]**

i Topography:

Intensity (nT) __________

Alignment of Geomagnetic Contours

1.25km radius of stranding site - parallel, perpendicular

ii Disturbances:

Any magnetic storms or sub-storms - YES/ NO

If YES: strength (K index value) __________

Date __________ Time __________

Note 3 - It is unlikely that geomagnetic data can be collected at stranding site. Topographical information can be obtained from aeromagnetic survey maps. Disturbance data can be obtained from nearest Magnetic Observatories.

8. **Description of the Animals:**

i Method used to mark individual animals - ________________________________

____

ii Number of Animals - alive males _______

females _______

- dead males _______

females _______

- unknown _______

iii Species Identification (use Baker 1983 - see last page)

____

iv Photographs YES / NO

(colour photograph with a scale and individual animal number, are of great value)

A list of photographs to be collected:

General views of stranding site

Views of Animals (select both representative and unusual animals)

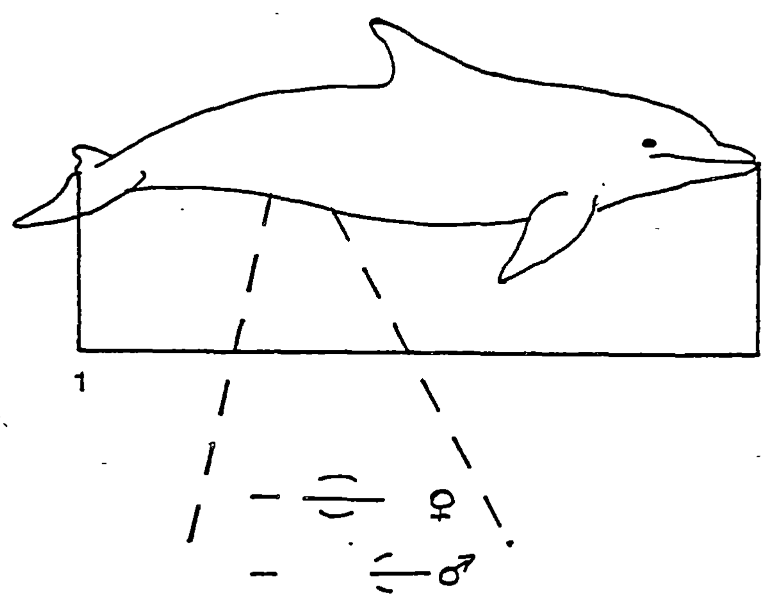
- general views of above, side and below animal
- details of head including blowholes, throat grooves and teeth or baleen
- details of genital region
- details of any unusual features, wounds, scars or marks

v External Features (see diagram)

a External Measurement

- total length, tip upper jaw to tail notch (cm) ______________

figure of general cetacean with detail of genital slits and how to take total length



b General

- colour patterns: (above, side and below)

____

____

- skin: wet, dry, blistering, peeling

- openings with any fluids coming out of any of the openings, (e.g. blood)

blowhole ____________________

mouth ____________________

genital slits ____________________

anus ____________________

- tail notch: present / absent
- dorsal fin: present / absent

c Head Region

- Baleen length (mm) (midway along jaw) ____________________

  colour, inside ____________________

  outside ____________________

- Teeth[4] number upper right __________

  upper left __________

  lower right __________

  lower left __________

  largest tooth height (mm) __________

  diameter (mm) __________

  wear degree: one, slight, moderate, extensive

  location: front , middle, back

Note 4 - if there are only 2 or 4 teeth in lower jaw **then** record;

distance from tip of jaw (mm) - __________

height (mm) __________ shape ____________________

- If **No** Teeth or Baleen

are there any sockets or signs to suggest their absences? YES / NO

If YES - number __________ location ______________

- Throat Grooves (count the groves in line with the joint of the lower jaw)

number __________ maximum length (cm) __________

location ____________________________________

- Blowholes one / two

vi Behaviour Record Kept YES / NO

record separately the behaviour of individuals, groups and any vocalizations, "care-giving" or co-ordinated behaviour. Collect eye- witness reports, include their name and contact address.

STAGES OF STRANDING OBSERVED

a.	Pre-stranding	YES	/	NO
b.	During act of stranding	YES	/	NO
c.	While stranded	YES	/	NO
d.	While being returned to water	YES	/	NO
e.	During and after release	YES	/	NO

Number of Sheets: __________

9. Date and Time:

stranding,	date:	____________________	time:	______________
discovery,	date:	____________________	time:	______________
examination,	date:	____________________	time:	______________

10. Observer: Name: ______________________________

Address: ____

____

phone: ______________

sign: ______________________________

Suggested References:

Baker, A.N., 1983; **Whales and Dolphins of New Zealand and Australia. An Identification Guide**; Victoria University Press, Wellington; 133pp..

Warneke, R.M., 1986; **Victorian Whale Rescue Plan, A contingency plan for strandings of cetaceans (whales, dolphins and porpoises) on the Victorian coastline**; Fisheries and Wildlife Service, Department of Conservation, Forests and Lands, Victoria, Melbourne.

Additional Comments:

Exact Location confirms details in Sheet I. The physical structure of the *Stranding Site* is described next, both on and offshore. This category is important as various aspects of the topography of stranding sites have been suggested as causes of strandings. *Weather* and *Sea Condition* are expansions of details in Sheet I. Some environmental details can not be collect on site so details should be obtained from the Weather Bureau.

Tidal Phase and *Moon Phase* are both related to the suggestion that the frequency of cetacean strandings varies with the stages of the monthly tidal cycle or phases of the moon. It is necessary to know the time when a stranding occurred for daily tidal cycle while date is sufficient to determine the stage of monthly tidal cycle or moon phase.

Geomagnetic Data has been requested because of the recent discovery that the earth's magnetic field may play a role in strandings (see Sections 2.3.3 and 4.4). The collection of geomagnetic data is highly specialized, so the data can be obtained from the relevant authorities after the event.

Description of the Animals covers species identity, number, sex, size, and behaviour of the animals. The identification of individuals is important for both rescue operations (it helps with the evaluation of the usefulness of techniques and success of the operation, as a whole) and in recording individual behaviours. The number of animals alive or dead when examined may indicate the overall condition of the animals. Comparing the conditions of animals as recorded in Sheets I and II, it may be possible to identify changes in their conditions due to the weather and/or time ashore. A list of photographs that should be taken of each stranding is provided.

The external features of the cetaceans are examined principally to established species identity. Further indications of the animals' condition and their size are included. Descriptions of any behaviour observed should be recorded.

EXAMINATION OF ANIMALS

The third stage involves the examination, in detail, of the animals involved in the stranding, including their health status and general biology. These examinations are important as much of the basic biology of cetaceans is still unknown, as well as providing information on possible causes of death and the strandings. In addition, strandings provide an opportunity to collect tissue samples to monitor the impact of pollution on cetaceans.

CETACEAN STRANDING DATA SHEET III
STRANDING EVENT DATA

INTRODUCTION

Sheet III is to be used in conjunction with Sheet II (Stranding Event Data) to collect data about animals involved in stranding. For live animals, only sections 1, 2, 4 and 5 should be completed. Layout of Sheet III is basically that used in collecting data from single animals. At large herd strandings it is advisable to select a sample of animals, including animals from all size and age groups at the stranding, if possible. Actual size of the sample will depend on number and experience of observers and size and number of animals.

Either fill in blanks or circle appropriate answer. Note more than one answer may be appropriate.

1. **Species:** (use Baker 1983 - see last page of form)

____

2. **Date and Time:**

stranding date: ____________ time: ____________

examination date: ____________ time: ____________

3. **External Features:**

i. NUMBER OF ANIMALS:

Male	mature	________	
	immature	________	
	unknown	________	
Female	mature	________	1
	immature	________	
	unknown	________	
Unknown		________	

Note 1 - record the number of females with active mammary glands ________

ii CONDITION OF ANIMALS

General number healthy ________ obviously unhealthy ________

unknown ________

wounds or injuries - location ______________________________

____

- describe ______________________________

____

iii EXTERNAL MEASUREMENTS: Animal's number ____________

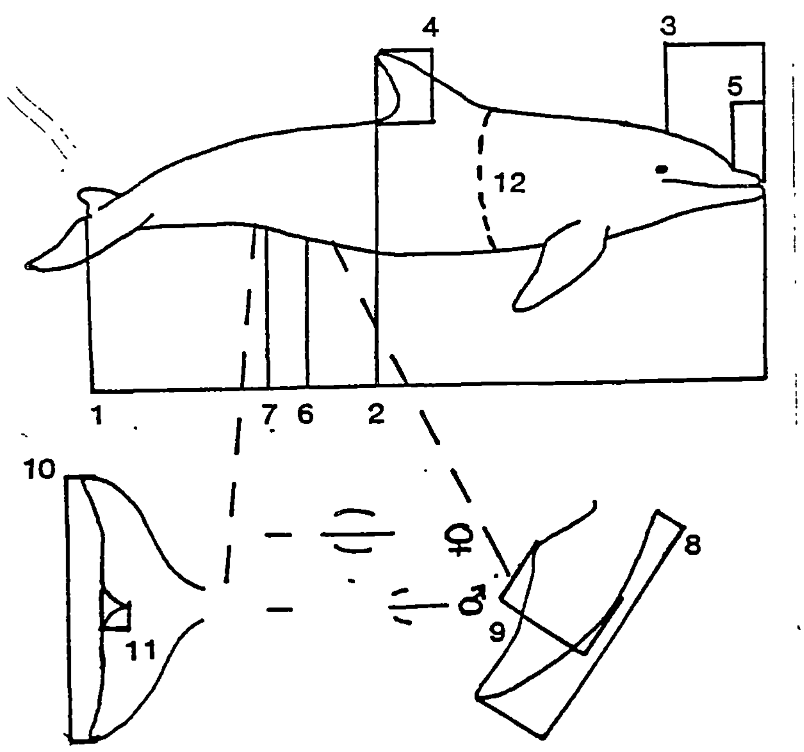
use only straight-line measurements except for measurement 12, see attached diagram for details of each measurement.

Additional recording sheets available for herd strandings (Sheet III Supplementary).

(measurements in millimetres)

1) total length, rostrum to tail notch ____________
2) rostrum to top of dorsal fin ____________
3) rostrum to blowhole ____________
4) height of dorsal fin ____________
5) rostrum to front of melon ____________
6) rostrum to centre of genital slit ____________
7) rostrum to centre of anus ____________
8) length of flipper (L or R) ____________
9) width of flipper (L or R) ____________
10) width of tail flukes ____________
11) depth of tail notch ____________
12) maximum girth ____________

Diagram of measurements to be taken from stranded cetaceans



4. Internal Examination:

Maximum information is obtained if examinations are conducted by experienced veterinarians or cetologists. If, however, such personnel are not available useful information can still be collected by personnel with some training in biology, such as wildlife research officers, inexperienced veterinarians and vertebrate zoologists. The local meat inspectors may be helpful, if no biologically trained personnel are available. The following questions are a guide for the examination.

Select animals that cover the full range of sizes and ages available.

i BLUBBER: location 1 2

colour ______________ ______________

thickness (mm) ______________ ______________

Describe location 1 ______________________________

location 2 ______________________________

Internal Parasites

Blubber Yes / No / Not examined

Muscle Yes / No / Not examined

Samples for Analysis (collected for toxicology, heavy metal and pesticide residues)

Blubber YES / NO

Muscles YES / NO

General Remarks: include any comments on any unusual features noted, also take samples where possible.

____

____

ii ABDOMINAL CAVITY

A *Reproductive Organs:*

Females Ovaries (freeze) collected YES / NO

Uterus, describe condition - ______________________________

____

____

Foetus - sex male / female, length (mm) ____________

Mammary glands - milk present / absent

Males Testes - length x width(mm): left ________ x ________

right ________ x ________

- weight (g) left __________ right __________

preserve section of one teste (L or R) by freezing.

Internal Parasites

Reproductive Organs Yes / No / Not examined

General Remarks: include any comments on any unusual features noted also take samples where possible.

____

____

B *Digestive System and Associated Organs*

Stomach Contents: (preserve in alcohol or by freezing)

Fore stomach - YES / NO

Hind stomach - YES / NO

Small intestine - YES / NO

Large intestine - YES / NO

Weight of Organs(g)

Liver: __________ Pancreas: ___________ Spleen: __________

Kidneys Left: ___________ Right: ___________

Internal Parasites

Stomach Yes / No / Not examined

Intestine Yes / No / Not examined

Kidneys Yes / No / Not examined

Liver Yes / No / Not examined

Samples for Analysis (collected for toxicology, heavy metal and pesticide residues)

Liver YES / NO

Kidney YES / NO

General Remarks: include any comments on any unusual features noted also take samples where possible.

____

____

iii THORACIC CAVITY

A. Lungs colour ____________________

water in airways YES / NO

Weight of Organs (g) ____________________

Internal Parasites

Lungs YES / NO / Not examined

Airways YES / NO / Not examined

B. Heart

Weight of Organ (g) ____________________

Internal Parasites

heart YES / NO / Not examined

major vessels YES / NO / Not examined

General Remarks: include any comments on any unusual features noted also take samples where possible.

____

____

iv HEAD

Internal Parasites

airways YES / NO / Not examined

middle ear YES / NO / Not examined

melon YES / NO / Not examined

brain YES / NO / Not examined

General Remarks: include any comments on any unusual features noted also take samples where possible.

____

____

5 **Observer:** Name of principal observer: ______________________

contact address: ____

______________________________________ phone: ______________

expertise related to cetacean strandings: ___________________________

names of other observers: ____________________________________

____

Number of Supplementary Sheets ____________________

sign: ______________________________

Suggested References:

Baker, A.N., 1983; **Whales and Dolphins of New Zealand and Australia. An Identification Guide**; Victoria University Press, Wellington; 133pp..

Warneke, R.M., 1986; **Victorian Whale Rescue Plan, A contingency plan for strandings of cetaceans (whales, dolphins and porpoises) on the Victorian coastline**; Fisheries and Wildlife Service, Department of Conservation, Forests and Lands, Victoria, Melbourne.

Additional Comments:

Data Sheet III aims to collect this biological data, given sufficient personnel and time. It is the most complex of the three data sheets and, therefore, requires the observers to have some biological skills and is the most time consuming. **Data Sheet III** is not a comprehensive outline of an examination of a stranded cetacean and if there are additional features that a specific observer considers interesting, or important, then they should be examined.

Since the information in this Data Sheet has no immediate use to the organisers of rescue operations then its collection should have a lower priority than rescuing animals. Further descriptions of the data that could be collected from internal examinations is available from many references, for example Norris (1961) and Warneke (1986).

Data Sheet III is divided into five categories. *Species* and *Date and Time* provide a reference to Sheets I and II. The third category, *External Features*, has greater detail than Sheet II. Again the number and sex of animals are recorded, with information about their maturity. Information about the condition of the animals is collected, including descriptions of any wounds or injuries.

Twelve external measurements are requested, all straight-line measurements except for the girth. The choice of measurements is an attempt to maximize the collection of morphometric data useful in determining species, age and sex differences for the minimum effort. To determining which measurements have the highest diagnostic value comparisons between all measurements from several individuals and several species should be conducted. Unfortunately, such data was not available to be able to conduct such an analysis in this study.

Internal Examination is the major category in **Data Sheet III**. The items are listed in the order usually followed in an examination. The level of information requested is restricted to that which a person with some expertise in autopsies, or biological examinations, could be expected to handle. Even grossly diseased, injured or malformed organs require the expertise and facilities of a veterinary pathology laboratory to determine the actual cause. A major function of the observer is to collect specimens, such as parasites, stomach contents or organs, from both apparently normal and unusual animals for later examination by experts.

Details about the expertise of the principal observer are included to assist in establishing the reliability of the data collected. In strandings involving more than one cetacean, the data collected from the additional animals should be recorded on separate paper and attached.

USE OF NEW DATA COLLECTION PROCEDURE

The three data sheets combine to form a data collection procedure, which aims to provide data covering the three principal areas of interest; the organization of rescue operations, investigations of causes of strandings and descriptions of cetacean biology. The priority is to return to the sea any cetaceans that are alive and still have a good chance of survival. The collection of scientific data should always comes second to the rescue operation, with the exception of data required as part of the rescue operations.

The relationships between the three data sheets, various authorities and a stranding are indicated in Figure III.1. The central role of the information recorded in **Data Sheet I** is clearly displayed. Notification of a stranding event usually comes from the public. It is important at this stage to obtain the basic details about the stranding event. This data is needed by the authorities to assist in deciding on the type of operation required, either rescue or data recovery.

If animals are alive then a rescue operation will begin and one of the earliest tasks is to confirm the data already collected. Collection of information about the stranding event, its site and confirmation of species identity are the aims of **Data Sheet II**. This data also is of interest to researchers investigating patterns, and possible causes, of strandings. **Data Sheet III** covers details about the animals, their biology and possible cause of death. The availability of personnel and time is a major limitation on data collection but if expertise is available to obtain more details than requested in **Data Sheet III** that should be collected. If limitations in personnel, time and access are reducing the collection of data then a sample of animals, containing both unusual and representative members of the herd, should be examined in as much detail as possible. The size of the sample will be related to the degree of limitation being imposed.

FIGURE III.1

The flow chart of the operational procedures for cetacean strandings with live and/or dead cetaceans to illustrate how the three Cetacean Stranding Data Sheets would be integrated into the overall operation.